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BOOKHAM, INC., a Delaware Corporation

UNITED STATES DISTRICT COURT

NORTHERN DISTRICT OF CALIFORNIA

SAN JOSE DIVISION

BOOKHAM, INC., a Delaware corporation, Plaintiff, v. JDS UNIPHASE CORP., a Delaware Corporation; AGILITY COMMUNICATIONS, INC., a Delaware corporation, and DOES 1-10, Defendants.	No. 5:08-CV-01275-RMW **FIRST AMENDED COMPLAINT FOR INTENTIONAL INTERFERENCE WITH PROSPECTIVE ECONOMIC ADVANTAGE, STATUTORY UNFAIR COMPETITION AND DECLARATORY JUDGMENT OF NONINFRINGEMENT, INVALIDITY, AND UNENFORCEABILITY** **DEMAND FOR JURY TRIAL**

Plaintiff, for its complaint herein, alleges as follows:

THE PARTIES

1. Plaintiff, Bookham, Inc. ("Bookham") is a corporation organized and existing under the laws of the State of Delaware, with its principal place of business at 2584 Junction Ave., San

Jose, California, 95134.

2. Defendant JDS Uniphase Corp. ("JDSU") is a corporation organized and existing under the laws of the State of Delaware, with its principal place of business at 430 N. McCarthy Boulevard, Milpitas, California, 95035.

3. Defendant Agility Communications, Inc. ("Agility Communications") is a corporation organized and existing under the laws of the State of Delaware. Agility Communications' address is listed with the California Secretary of State as 475 Pine Avenue, Goleta, California, 93117. Agility Communications' registered agent is located at 430 N. McCarthy Boulevard, Milpitas, California, 95035. Agility Communications is a wholly-owned subsidiary of JDSU.

4. The true names or capacities, whether individual, corporate, associate, or otherwise, of defendants named as DOES 1 through 10 inclusive, are unknown to Bookham, and Bookham therefore sues these defendants by fictitious names. Bookham will seek leave to amend this complaint to include the true names and capacities of the DOE defendants when ascertained.

JURISDICTION

5. This is an action under section 17200 *et seq.* of the Business & Professions Code of the State of California. The Defendants are subject to jurisdiction in the State of California because they expressly, intentionally, and knowingly directed unlawful actions at a corporation headquartered in California and because these intentional actions caused harm in California. In addition, JDSU is headquartered in the Northern District of California.

6. This is also an action arising under the laws of the State of California in which Bookham seeks to recover for intentional interference with economic advantage. The Defendants are subject to jurisdiction in the State of California because they expressly, intentionally, and knowingly directed actions at a corporation headquartered in California and because these intentional actions caused harm in California.

7. This is also an action for a declaratory judgment of noninfringement, invalidity, and unenforceability of United States Patents Nos. 6,658,035, 6,654,400, 6,687,278, and related patents. The action arises under the Declaratory Judgment Act, 28 U.S.C. §§ 2201-2202, and the

patent laws of the United States, including Title 35, United States Code. This Court has original jurisdiction over the subject matter of this action under 28 U.S.C. § 1338.

VENUE

8. Venue is proper in this Court under 28 U.S.C. § 1391 because JDSU resides in this judicial district and because a substantial part of the events giving rise to Bookham's claims occurred in this judicial district.

INTRADISTRICT ASSIGNMENT

9. This patent action is in an excepted category for Local Rule 3-2(c), Assignment of a Division, and will be assigned on a district-wide basis.

FACTUAL ALLEGATIONS

10. JDSU purports to own United States Patent Nos. 6,658,035 (the " '035 patent"), 6,654,400 (the " '400 patent"), and 6,687,278 (the " '278 patent"), collectively referred to as the "Patents" and attached as Exhibits 1, 2 and 3. Records at the United States Patent and Trademark Office ("USPTO") list Agility Communications as the present assignee for the Patents.

11. JDSU acquired Agility Communications in November 2005 and, on information and belief, acquired at least some rights in the Patents.

12. JDSU represents that it has the right to enforce the Patents.

13. JDSU asserts that the technology covered by the Patents is proliferating through the optics industry.

14. JDSU asserts that Bookham's tunable laser products, which are used for high-speed data communications, are covered by the '035 patent.

15. The '400 and '278 patents are related to the '035 patent and claim related subject matter to the '035 patent.

16. JDSU has accused Bookham in writing of infringing the claims of the '035 patent.

17. JDSU employees or agents have informed Bookham's customers and potential customers that Bookham's tunable laser products infringe the claims of the '035 patent so that those customers and potential customers would purchase JDSU tunable laser products instead of Bookham tunable laser products.

18. JDSU has informed Bookham's customers and potential customers that they will infringe the claims of the '035 patent by purchasing or using Bookham's tunable laser products, and should, therefore, purchase JDSU's tunable laser products instead.

19. JDSU has pressured Bookham's customers and potential customers to purchase its tunable laser products by claiming that Bookham's tunable laser products may not be available for sale in the future because they allegedly infringe the claims of the '035 patent.

20. After Bookham presented evidence to JDSU demonstrating the invalidity and unenforceability of the Patents, JDSU continued pressuring Bookham's customers and potential customers by repeating its infringement threats.

21. JDSU's assertions of infringement have damaged Bookham and continue to damage Bookham. JDSU's repeated threats to Bookham's customers and potential customers have negatively impacted Bookham's sales and interaction with its customers and potential customers. Bookham has suffered irreparable injury, including increased transactional costs, damage to its corporate reputation, and damage to its brand as a result of JDSU's conduct.

22. On information and belief, when JDSU made infringement threats regarding Bookham's tunable laser products, it knew or should have known that the '035, '400, and '278 patents are invalid and/or unenforceable. Specifically, JDSU's employees and agents knew, or should have known, at least the following:

(a) Thomas Beck Mason, Gregory A. Fish, and Larry A. Coldren are named as inventors on the '035, '400, and '278 patents.

(b) On August 6, 1998, Thomas Beck Mason, Gregory A. Fish, Steven P. DenBaars, and Larry A. Coldren jointly published an article titled "Ridge Waveguide Sampled Grating DBR Lasers with 22-nm Quasi-Continuous Tuning Range" in Volume 10, Issue No. 9 of the journal Photonics Technology Letters (hereafter the "Mason Publication").

(c) The Mason Publication discloses optimized waveguide structures and improved regrowth techniques that enabled the authors to extend the tuning range of conventional ridge waveguide DBR laser diodes to greater than 6 nm and, in SGDBR configuration, to greater than 22 nm.

(d) According to the Mason Publication, these tuning ranges were the "largest ever reported for a ridge waveguide structure."

(e) The broadly tunable laser disclosed in the Mason Publication is depicted in Figure 1B of the '035, '400, and '278 patents.

(f) Multiple claims in each of the '035, '400, and '278 patents recite as a claim element the broadly tunable laser disclosed in the Mason Publication.

(g) On information and belief, Steven P. DenBaars is a co-inventor of the broadly tunable laser assembly that is disclosed in the Mason Publication and recited as an element in the claims of the '035, '400, and '278 patents.

(h) On information and belief, Mason, Fish, and/or Coldren knew at the time they filed the applications that matured into the '035, '400, and '278 patents that Steven P. DenBaars was a co-inventor of the inventions claimed therein.

(i) The '035, '400, and '278 patents are therefore invalid under 35 U.S.C. § 1 *et seq*.

(j) Additionally, Bookham is informed and believes and, based thereon, alleges that the named inventors of the '035, '400, and '278 patents and/or their attorneys, employees and agents, with intent to deceive, failed to disclose material prior art to the USPTO during the prosecution of the applications which issued as the '035, '400, and '278 patents.

(k) The earliest application date of the '035, '400, and '278 patents is September 2, 1999.

(l) The Mason Publication qualifies as a prior art printed publication to the Patents under 35 U.S.C. § 102(b), because it was published in this country more than one year prior to September 2, 1999, the earliest application date for the '035, '400, and '278 patents. The Mason Publication also qualifies as prior art under 35 U.S.C. § 102(a).

(m) On information and belief, the authors of the Mason Publication also presented the Mason Publication and distributed copies of the publication at the International Semiconductor Laser Conference '98 in Nara, Japan, and elsewhere.

(n) The information disclosed in the Mason Publication is not cumulative to

information made of record during prosecution of the applications that issued as the ‘035, ‘400, and ‘278 patents.

(o) The Mason Publication is material prior art under 37 C.F.R. § 1.56 at least because, when combined with other art, it establishes a prima facie case of unpatentability of one or more claims contained in each of the ‘035, ‘400, and ‘278 patents. A reasonable examiner would have considered the information disclosed in the Mason Publication to be important in deciding whether to allow one or more claims in the applications for the ‘035, ‘400, and ‘278 patents to issue.

(p) The named inventors of the ‘035, ‘400, and ‘278 patents and/or their attorneys, employees and agents knew that the Mason Publication was material prior art to the inventions claimed in the applications that issued as the ‘035, ‘400, and ‘278 patents at the time they filed their patent applications and while those applications were pending before the USPTO.

(q) On information and belief, despite their knowledge of the Mason Publication and its materiality to the subject matter of the ‘035, ‘400, and ‘278 patents, and despite their duty to disclose material information to the USPTO, the named inventors and/or their attorneys, employees, and agents knowingly and intentionally withheld the Mason Publication from the USPTO, with the intent to deceive the USPTO regarding the patentability of the claims of the ‘035, ‘400, and ‘278 patents. As a result, the ‘035, ‘400, and ‘278 patents are unenforceable for inequitable conduct.

(r) Each of the named inventors, including Coldren in particular, is a prolific author in the same field of endeavor as the Patents. On information and belief, the named inventors authored or co-authored other prior art publications that were relevant to the patentability of the Patents that also were not disclosed to the USPTO during prosecution of the Patents.

FIRST CLAIM FOR RELIEF

INTENTIONAL INTERFERENCE WITH PROSPECTIVE ECONOMIC ADVANTAGE UNDER CALIFORNIA COMMON LAW

23. Bookham incorporates paragraphs 1-22 as though set forth fully and completely herein.

24. On information and belief, JDSU intentionally interfered with prospective economic relations between Bookham and its customers and potential customers.

25. On information and belief, JDSU has engaged in unfair, unlawful, or fraudulent business practices, and in untrue or misleading advertising by accusing Bookham's tunable laser products of infringing the claims of the '035 patent, which JDSU knows, or should know, is invalid and unenforceable.

26. Bookham has been injured as a result of JDSU's unfair, unlawful, and fraudulent business practices and untrue or misleading advertising, and will continue to be injured until JDSU is enjoined from tortiously interfering with Bookham's existing and potential business relationships.

27. Bookham is entitled to an injunction enjoining JDSU from continuing its intentional interference with Bookham's prospective economic advantage and an award of compensatory and punitive money damages.

SECOND CLAIM FOR RELIEF

STATUTORY UNFAIR COMPETITION UNDER CALIFORNIA BUSINESS AND PROFESSIONAL CODE § 17200, ET SEQ.

28. Bookham incorporates paragraphs 1-22 as though set forth fully and completely herein.

29. On information and belief, JDSU has engaged in unfair, unlawful or fraudulent business practices, and in untrue or misleading advertising by accusing Bookham's tunable laser products of infringing the claims of the '035 patent, which JDSU knows, or should know, is invalid and unenforceable.

30. On information and belief, JDSU's unlawful conduct has resulted in JDSU's unjust

enrichment.

31. Upon information and belief, JDSU is likely to continue its allegations of patent infringement unless enjoined by this Court.

32. Bookham has suffered reputational and monetary damages as a result of JDSU's unlawful conduct.

33. Bookham is entitled to an injunction enjoining JDSU from making any threats of, or charging or asserting or instituting any action for, infringement of the claims of the Patents against Bookham, or anyone in privity with Bookham, including its suppliers, successors, assigns, agents, customers, and/or potential customers, as well as restitution damages for the harm JDSU has inflicted.

THIRD CLAIM FOR RELIEF

DECLARATORY JUDGMENT OF NONINFRINGEMENT OF

U.S. PATENT NOS. 6,658,035, 6,654,400, AND 6,687,278

34. Each of paragraphs 1-22 is incorporated herein by reference.

35. There is an actual and justiciable controversy between Bookham and JDSU as to whether the use, making, sale, offering for sale, or importation of the Bookham tunable laser products infringes any valid or enforceable claim of the '035, '400, and '278 patents.

36. JDSU has accused Bookham's tunable laser products of infringing the claims of the '035 patent.

37. The '400 and '278 patents are related to the '035 patent and claim related subject matter to the '035 patent.

38. Bookham currently manufactures the Bookham tunable laser products for sale and use in the United States and offers for sale and sells tunable laser products in the United States.

39. Bookham's tunable laser products do not infringe any valid, enforceable claim of the '035, '400 and '278 patents.

40. JDSU's allegations of patent infringement have caused, and will continue to cause, damage to Bookham.

41. Upon information and belief, JDSU is likely to continue its allegations of patent

infringement.

42. Bookham is entitled to a declaratory judgment of noninfringement of the claims of the '035, '400, and '278 patents.

FOURTH CLAIM FOR RELIEF

DECLARATORY JUDGMENT OF INVALIDITY OF

U.S. PATENT NOS. 6,658,035, 6,654,400, AND 6,687,278

PURSUANT TO 35 U.S.C. §§ 101, 102, 103, 112 AND/OR 116

43. Each of paragraphs 1-22 is incorporated herein by reference.

44. There is an actual and justiciable controversy between Bookham and JDSU as to whether each and every claim of the '035, '400, and '278 patents is valid.

45. Bookham contends that one or more claims of the '035, '400, and '278 patents is invalid for failure to comply with the requirements of 35 U.S.C. §§ 101, 102, 103, 112 and/or 116.

46. On information and belief, JDSU contends that each claim of the '035, '400, and '278 patents is valid and enforceable.

47. The assertions made by JDSU that Bookham is infringing the claims of the '035 patent have caused, and will continue to cause, irreparable harm to Bookham.

48. Bookham is entitled to a declaratory judgment of invalidity of the claims of the '035, '400, and '278 patents.

FIFTH CLAIM FOR RELIEF

DECLARATORY JUDGMENT OF UNENFORCEABILITY OF

U.S. PATENT NOS. 6,658,035, 6,654,400, AND 6,687,278

AND RELATED PATENTS AND PATENT APPLICATIONS

49. Each of paragraphs 1-22 is incorporated herein by reference.

50. There is an actual and justiciable controversy between Bookham and JDSU as to whether the '035, '400, and '278 patents and/or related patents and patent applications are unenforceable, in whole or in part, due to inequitable conduct before the USPTO by persons involved in the prosecution of the '035, '400, and '278 patents and related patents and patent applications.

51. Bookham contends that the claims of the ‘035, ‘400, and ‘278 patents and related patents and patent applications are unenforceable because the applicants for the ‘035, ‘400, and ‘278 patents or their agents knowingly and intentionally failed to comply with 37 C.F.R. § 1.56 during the prosecution of the applications that led to the issuance of the ‘035, ‘400, and ‘278 patents, related applications, and applications upon which priority is claimed.

52. Under the doctrine of infectious unenforceability, the inequitable conduct committed by persons involved in the prosecution of the ‘035, ‘400, and ‘278 patents and related patents and patent applications infects and renders unenforceable all related patents and patent applications.

53. Bookham is entitled to a declaratory judgment of unenforceability of the claims of the ‘035, ‘400, and ‘278 patents.

54. Under the doctrine of infectious unenforceability, Bookham is entitled to a declaratory judgment of unenforceability of the claims of each patent and patent application that is related to, or that claims priority from, the ‘035, ‘400, or ‘278 patents.

PRAYER FOR RELIEF

WHEREFORE, Bookham prays that:

(a) Agility, JDSU, its officers, agents, servants, employees, attorneys, assignees, and those persons in active concert or participation with them, be enjoined from making any threats of, or charging or asserting or instituting any action for, infringement of the ‘035, ‘400, and ‘278 patents against Bookham, or anyone in privity with Bookham, including its suppliers, successors, assigns, agents, customers, and/or potential customers;

(b) Agility and JDSU be ordered to pay restitution damages for the harm they have caused Bookham;

(c) Bookham recover compensatory damages against Agility and JDSU;

(d) Bookham recover punitive damages against Agility and JDSU;

(e) A declaratory judgment be entered that manufacturing, using, offering for sale, selling, or importing the Bookham tunable laser products does not infringe, induce the infringement of, or contribute to the infringement of any claim of the ‘035, ‘400, and ‘278 patents;

(f) A declaratory judgment be entered that each claim of the '035, '400, and '278 patents is invalid;

(g) A declaratory judgment be entered that each claim of the '035, '400, and '278 patents is unenforceable;

(h) A declaratory judgment be entered that, according to the doctrine of infectious unenforceability, the claims of each patent and patent application that is related to, or that claims priority from, the '035, '400, or '278 patents is unenforceable;

(i) This case be declared an exceptional case under 35 U.S.C. § 285, and that Bookham be awarded its attorney's fees in this action; and

(j) Bookham be awarded all other and further relief as the Court deems just and proper in this case.

Dated: June 30, 2008

COOLEY GODWARD KRONISH LLP

By: */s/ Wayne O. Stacy*
Wayne O. Stacy

Attorneys for Plaintiff
BOOKHAM, INC.

JURY DEMAND

Plaintiff respectfully requests a jury trial on all issues triable thereby.

Dated: June 30, 2008

COOLEY GODWARD KRONISH LLP

By: *__/s/ Wayne O. Stacy__*
Wayne O. Stacy
Attorneys for Plaintiff
Bookham, Inc.

302820 v2/CO

EXHIBIT 1

US006658035B1

(12) **United States Patent**
Mason et al.

(10) **Patent No.: US 6,658,035 B1**
(45) **Date of Patent: *Dec. 2, 2003**

(54) **TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL AMPLIFIER**

(75) Inventors: **Thomas Beck Mason**, Middletown, NJ (US); **Gregory Fish**, Santa Barbara, CA (US); **Larry Coldren**, Santa Barbara, CA (US)

(73) Assignee: **Agility Communications, Inc.**, Goleta, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 243 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **09/614,375**

(22) Filed: **Jul. 12, 2000**

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/614,377, filed on Jul. 12, 2000, which is a continuation-in-part of application No. 09/614,895, filed on Jul. 12, 2000, now Pat. No. 6,349,106, which is a continuation-in-part of application No. 09/614,378, filed on Jul. 12, 2000, which is a continuation-in-part of application No. 09/614,376, filed on Jul. 12, 2000, which is a continuation-in-part of application No. 09/614,674, filed on Jul. 12, 2000, which is a continuation-in-part of application No. 09/614,195, filed on Jul. 12, 2000, which is a continuation-in-part of application No. 09/614,665, filed on Jul. 12, 2000, which is a continuation-in-part of application No. 09/614,224, filed on Jul. 12, 2000.

(60) Provisional application No. 60/152,072, filed on Sep. 2, 1999, provisional application No. 60/152,049, filed on Sep. 2, 1999, and provisional application No. 60/152,038, filed on Sep. 2, 1999.

(51) **Int. Cl.**[7] **H01S 5/026**
(52) **U.S. Cl.** **372/50**; 372/43
(58) **Field of Search** 372/50, 43

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,896,325 A * 1/1990 Coldren 372/20
5,084,894 A * 1/1992 Yamamoto 372/50
5,088,105 A 2/1992 Scifres et al. 372/92

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

EP	1 539 028	1/1979	.... H01S/3/02
EP	0 620 475 A	3/1994	.... G02F/1/313

OTHER PUBLICATIONS

Bar–Chaim, N. et al., "Monolithic Optoelectronic Integration of a GaAIAs Laser, a Field–Effect Transistor, and a Photodiode", *Applied Physics Letters, US, American Institute of Physics*, May 15, 1984, vol. 44, No. 10, pp. 941–943.

Koch, T.L., "Semiconductor Photonic Integrated Circuits", *IEEE Journal of Quantum Electronics*, Mar. 27, 1991, No. 3, pp. 641–653.

Byoung–Sung, K. et al., "Dynamic Analysis of Widely Tunable Laser Diodes Integrated with Sampled–and–Chirped–Grating Distributed Bragg Reflectors and an Electroabsorption Modulator", *IEICE Trans Electron*, Aug. 1998, vol. E81–C, No. 8, pp. 1342–1349.

San–Liang, L. et al., "Sampled Grating DBR Laser Arrays with Adjustable 0.8/1.6–nm Wavelength Spacing", *IEEE Photonics Technology Letters*, Aug. 1999, vol. 11, No. 8, pp. 955–957.

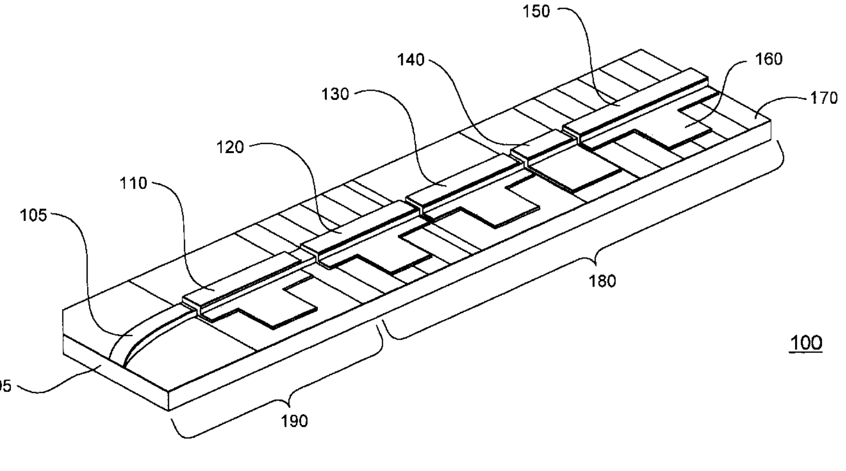
Jayaraman, V. et al., "Theory, Design, and Performance of Extended Tuning Range Semiconductor Lasers with Sampled Gratings", *IEEE Journal of Quantum Electronics*, Jun. 29, 1993, vol. 29, No. 6, pp. 1824–1834.

Primary Examiner—Paul Ip
Assistant Examiner—Jeffrey N. Zahn
(74) *Attorney, Agent, or Firm*—Gates & Cooper LLP

(57) **ABSTRACT**

A laser assembly includes an epitaxial structure formed on a substrate. A separately controllable tunable laser resonator and external optical amplifier are formed in the epitaxial structure. At least a portion of the laser and amplifier share a common waveguide, which may have non-uniform optical or geometrical properties along the waveguide centerline or across a normal to the centerline.

82 Claims, 7 Drawing Sheets



U.S. PATENT DOCUMENTS

5,145,792	A	*	9/1992	Hirata	438/36
5,253,314	A	*	10/1993	Alferness et al.	385/40
5,274,649	A	*	12/1993	Hirayama et al.	372/20
5,325,392	A	*	6/1994	Tohmori et al.	372/96
5,452,118	A	*	9/1995	Maruska	359/191
5,479,539	A		12/1995	Goldsmith et al.	385/14
5,525,541	A		6/1996	Krauz et al.	437/161
5,539,571	A	*	7/1996	Welch et al.	359/344
5,625,636	A		4/1997	Bryan et al.	372/50
5,674,778	A		10/1997	Lee et al.	437/126
5,715,268	A		2/1998	Lang et al.	372/50
5,742,045	A		4/1998	Parker et al.	250/214
5,838,714	A	*	11/1998	Delorme	372/96
6,031,851	A	*	2/2000	Shimizu et al.	372/18
6,208,454	B1	*	3/2001	Koren et al.	359/326
6,349,106	B1	*	2/2002	Coldren	372/50

* cited by examiner

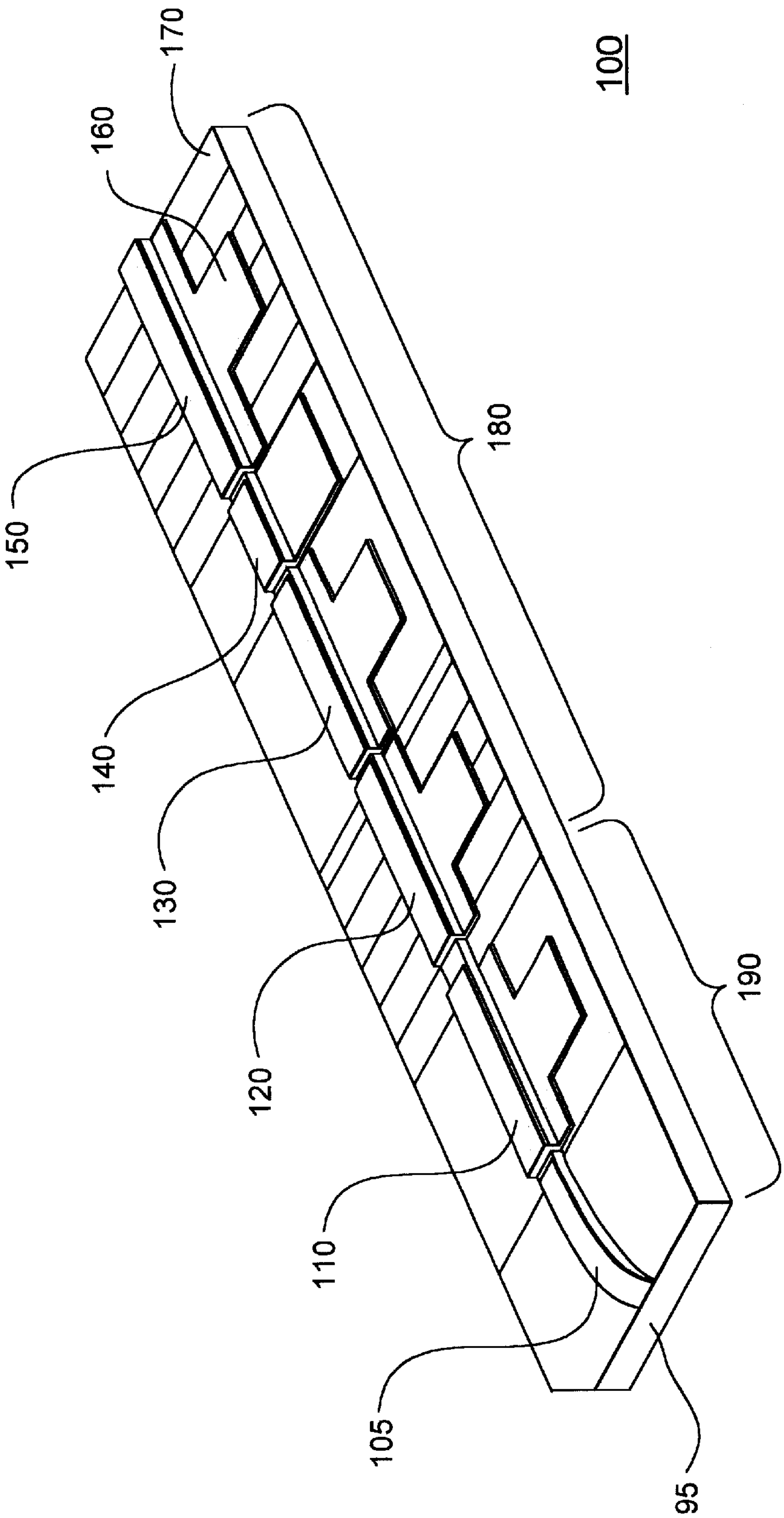
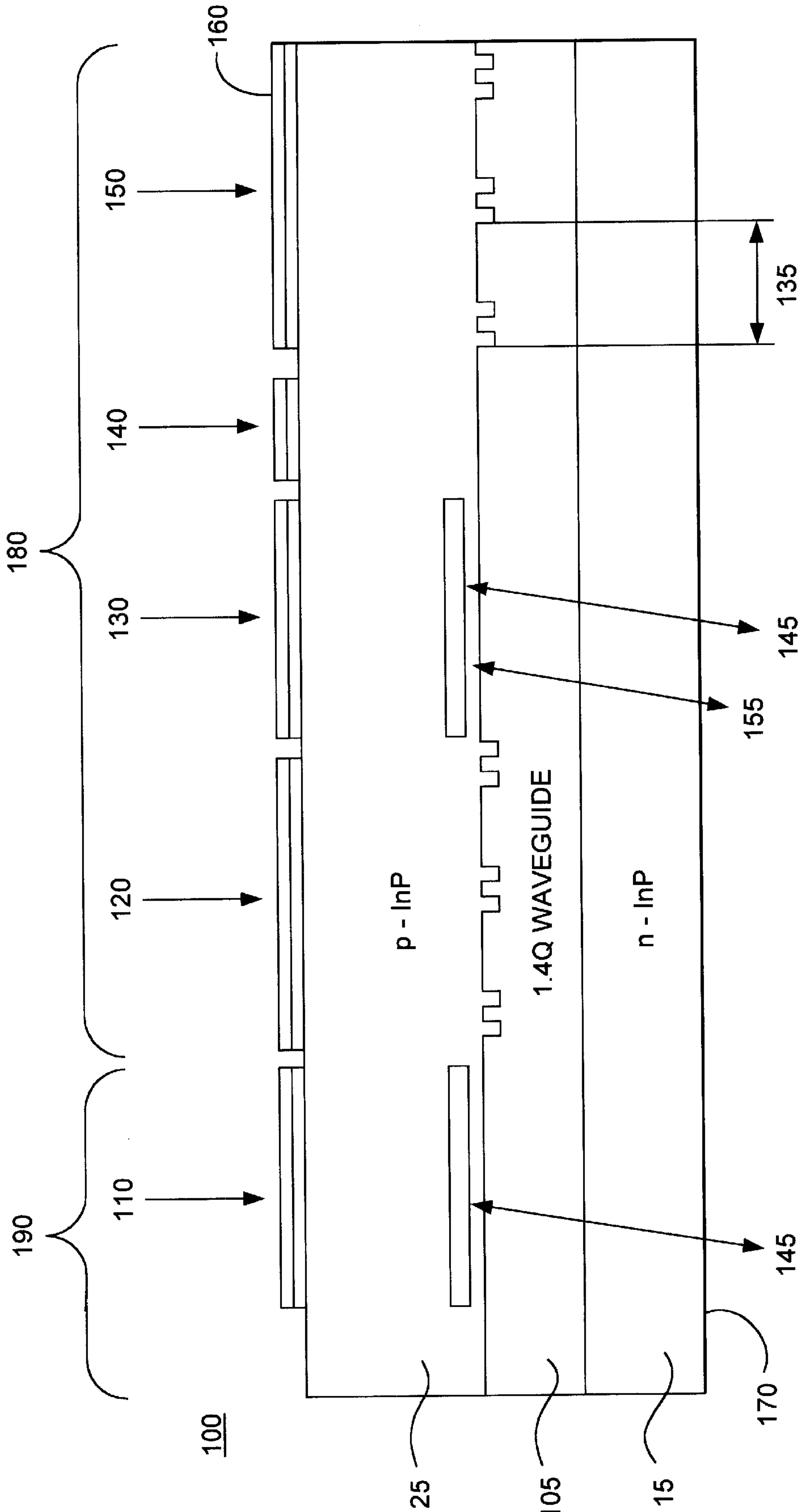


FIG. 1A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150
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120
110
180
190
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p - InP
1.4Q WAVEGUIDE
n - InP
100
125
105
115
170

FIG. 1B

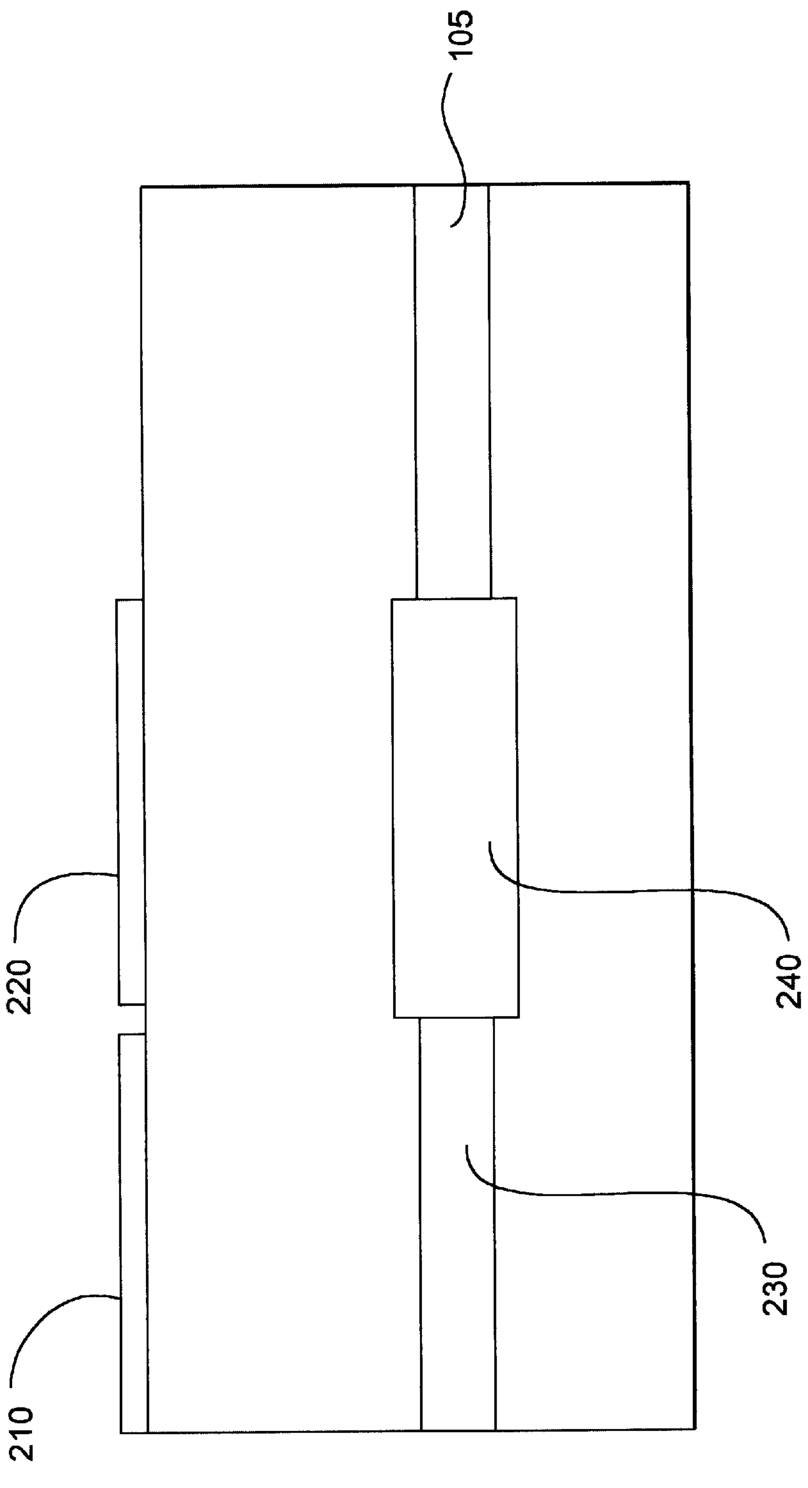

FIG. 2A

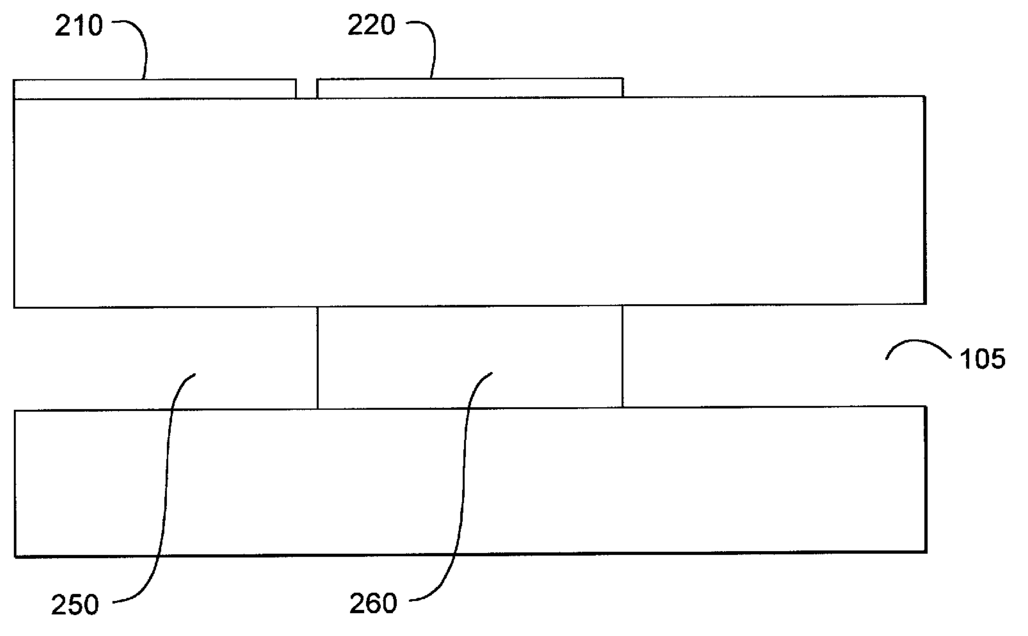

FIG. 2B

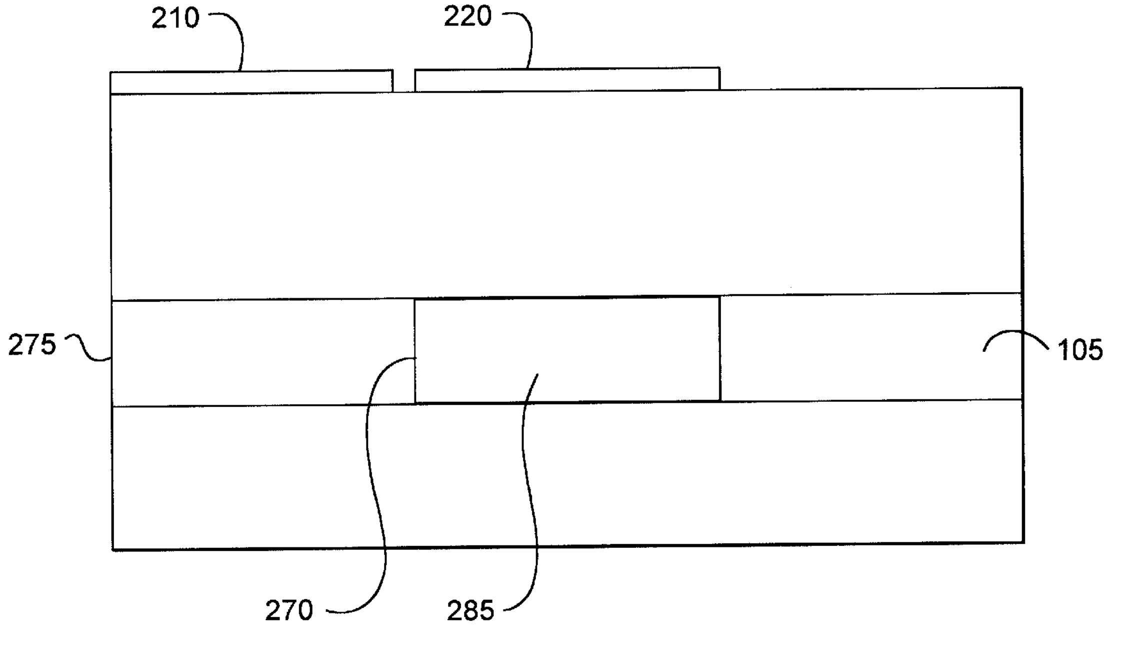

FIG. 2C

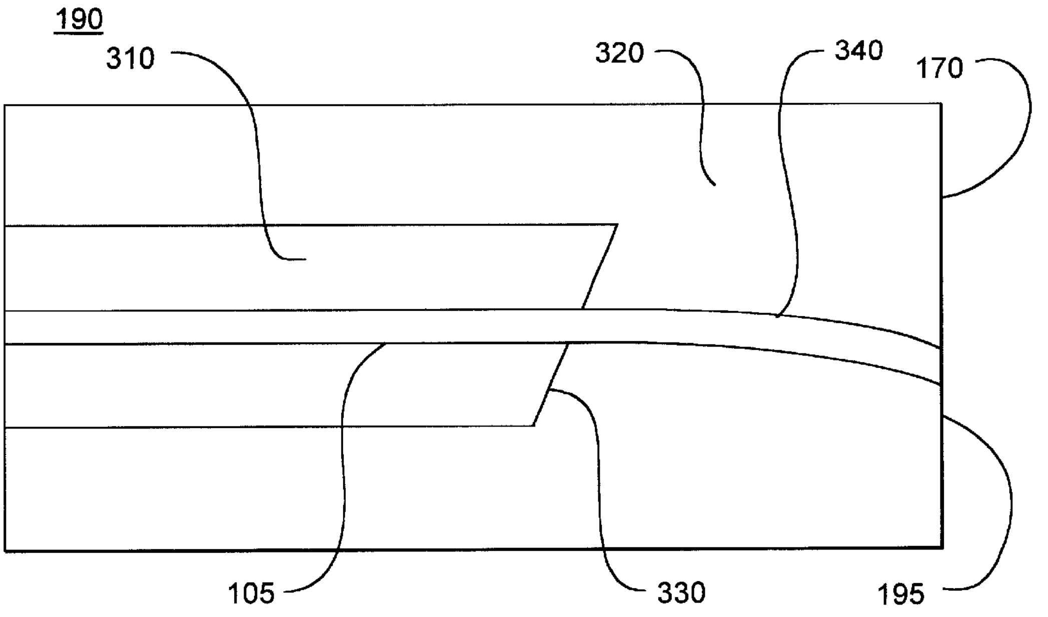

FIG. 3A

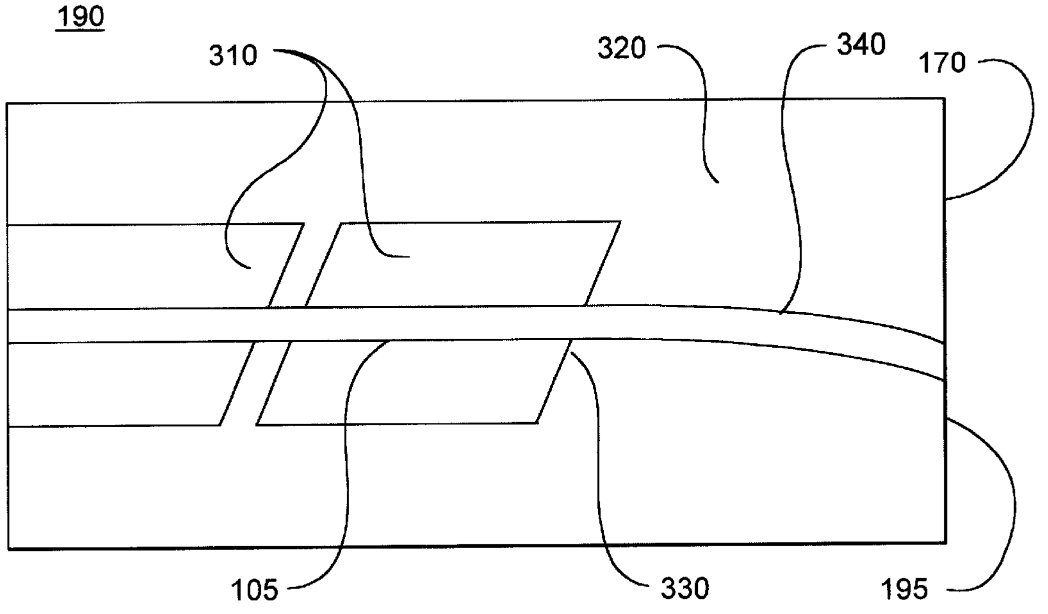

FIG. 3B

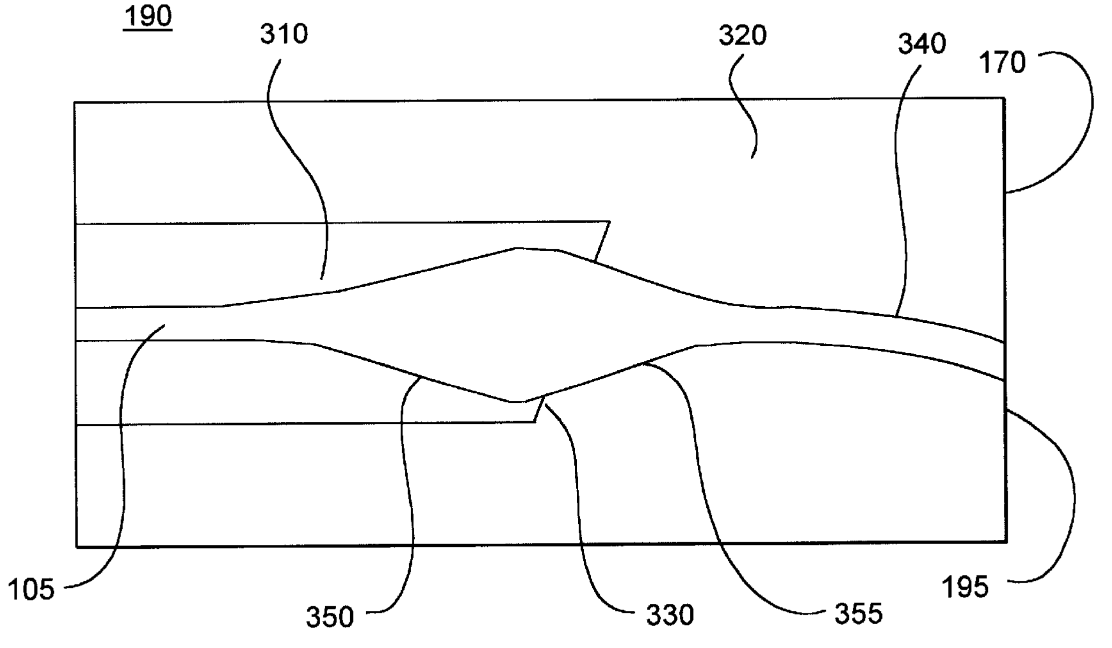

FIG. 3C

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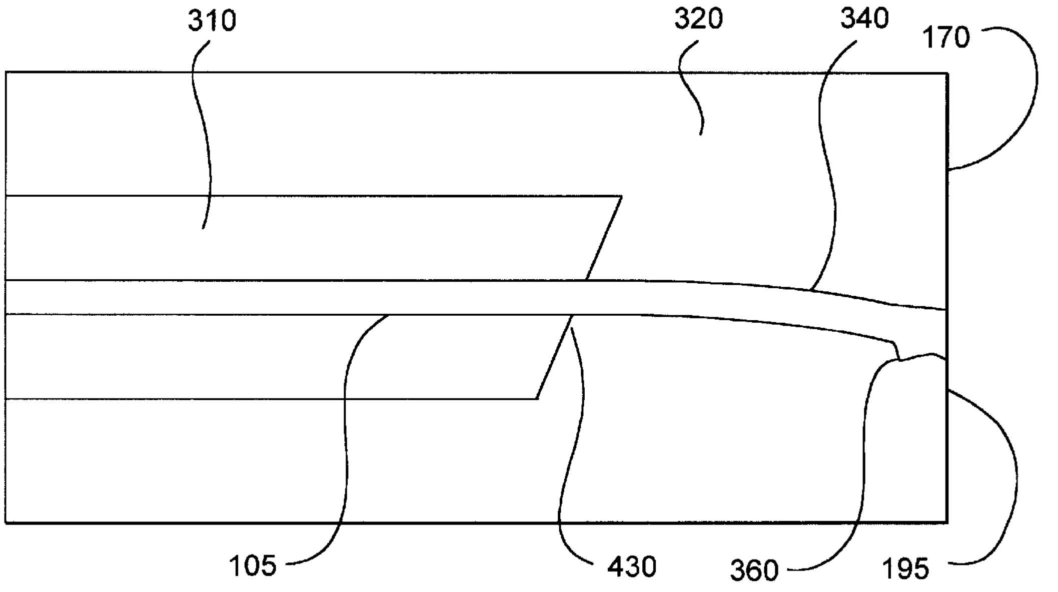

FIG. 3D

TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL AMPLIFIER

This application is continuation-in-part and claims the benefit of priority of U.S. provisional application Ser. No. 60/152,072,filed Sep. 2, 1999, U.S. provisional application Ser. No. 60/152,049, filed Sep. 2, 1999, U.S. provisional application Ser. No. 60/152,038, filed Sep. 2, 1999, which applications are fully incorporated by reference herein. This application is also a continuation-in-part of U.S. Ser. Nos. 09/614/377, 09/614,895 (now U.S. Pat. No. 6,349,106, issued Feb. 19, 2002), Ser. No. 09/614,674, Ser. No. 09/614, 378, Ser. No. 09/614,376, Ser. No. 09/614,195, Ser. No. 09/614,665 and Ser. No. 09/614,224, which applications are filly incorporated by reference herein.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to laser assemblies, and more particularly to a widely tunable laser assembly with an integrated optical amplifier.

2. Brief Description of the Related Art

Thin fibers of optical materials transmit light across a very broad frequency bandwidth and therefore communications data from a light source may be transmitted over such fibers over broad frequency ranges. At any particular frequency, a laser source must have high output power, narrow laser linewidth and good transmission performance through great distances of optical fiber.

In higher bandwidth communications systems, where many frequencies of laser light are transmitted along a fiber, there may be one or several laser sources. While a tunable laser source would be preferred, higher data capacity systems presently use multiple laser sources operating on different frequency channels to cover the wide fiber transmission bandwidth. This is the case since appropriate laser sources are presently incapable of rapid, electronic frequency tuning without attendant deterioration of other significant figures-of-merit.

For example, at a fixed frequency, sampled grating distributed Bragg reflector (SGDBR) lasers have the high output power, narrow laser linewidth and good transmission performance necessary for an optical data network. While some SGDBR lasers can be rapidly tuned over more than 100 different transmission channels, two problems nevertheless prevent these devices from being employed in fiber optic communication systems. The most significant problem is the significant absorption of the mirror material. The resulting large cavity losses act to make the laser output power insufficient for the requirements of a present-day communications system. A second problem is that the output power and frequency tuning are dependent on each other. This coupling results in inadequate controllability for a present-day communications system.

What is needed, instead, is a device with a combination of sufficiently high output power for a high-bandwidth optical communications network and with frequency tuning controllability substantially independent of output power controllability.

SUMMARY

Accordingly, an object of the present invention is to provide an integrated laser assembly that includes a tunable solid state laser and optical amplifier where all of the elements are fabricated in a common epitaxial layer structure.

Another object of the present invention is to provide an integrated laser assembly that includes a tunable solid state laser and optical amplifier with an output mode conditioned for transmission in an optical fiber.

Another object of the present invention is to provide an integrated laser assembly that includes a tunable laser and optical amplifier reducing optical feedback from the amplifier to the laser.

A further object of the present invention is to provide a tunable, integrated laser assembly where laser frequency control and output power control are substantially independent.

These and other objects of the present invention are achieved in a laser assembly that includes an epitaxial structure formed on a substrate. A tunable laser resonator and a separately controllable optical amplifier are formed in the common epitaxial structure.

The amplifier is positioned outside of the laser resonator cavity to receive and adjust an output received from the laser, however, at least a portion of the laser and amplifier share a common waveguide.

In different embodiments of the present invention, properties of the common waveguide such as optical properties, or centerline curvature or cross-sectional are non-uniform along the waveguide centerline or non-uniform across a normal to the centerline.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1A** is a block diagram of a laser assembly that illustrates different functional elements of a laser assembly.

FIG. **1B** is a cross-sectional view of one embodiment of a widely tunable laser assembly of the present invention and the integration of materials with differing optical properties by an offset quantum well technique.

FIG. **2A** is a cross-sectional view of one embodiment of an amplifier illustrating several layer structures and the integration of two materials with differing optical properties by a selected area growth technique.

FIG. **2B** is a cross-sectional view of the FIG. **2** assembly illustrating one embodiment for the integration of materials with differing optical properties by a disordered well technique.

FIG. **2C** is a cross-sectional view of one embodiment of an amplifier illustrating one embodiment for the integration of several different band gap materials by a butt joint regrowth technique.

FIG. **3A** is a cross-sectional view of one embodiment of the FIG. **1** optical amplifier element where a portion of the waveguide is curved and an interface between an active and a passive section is oblique.

FIG. **3B** is a cross-sectional view of one embodiment of the FIG. **1** optical amplifier element where the amplifier includes a plurality of gain sections.

FIG. **3C** is a cross-sectional view of one embodiment of the FIG. **1** optical amplifier element where the amplifier includes a flared waveguide.

FIG. **3D** is a cross-sectional view of one embodiment of the FIG. **1** optical amplifier element where the amplifier includes a waveguide mode adapter.

DETAILED DESCRIPTION

FIG. **1A** shows a schematic of an embodiment of the invention. In FIG. **1A**, laser assembly **100**, waveguide **105**, amplifier gain section **110**, front resonator mirror **120**, laser

gain section **130**, laser phase control section **140**, back mirror **150** and electrical contact **160**, epitaxial structure **170**, laser **180**, optical amplifier **190** and output facet **195** are shown.

In FIG. **1**A, laser assembly **100** comprises an integration of a laser and an optical amplifier, with the optical amplifier located external to the laser cavity. Front resonator mirror **120**, laser gain section **130**, laser phase control section **140**, and back mirror **150** form a SODBR-type laser **180** in epitaxial structure **170**. The front and back mirrors define a laser cavity. Amplifier gain section **110** and a portion of waveguide **105** define optical amplifier **190**.

As shown in FIG. **1**A, despite being external to the laser cavity, the optical amplifier shares a common epitaxial structure **170** with the laser. Epitaxial structure **170** is formed on a substrate (not shown) by processes well-known in the art of semiconductor fabrication. By tailoring optical properties (such as band gap) of different portions of the epitaxial structure, both optically active and optically passive sections can be fabricated in a common structure. Examples of optically active sections of the embodiment shown in FIG. **1** are gain sections **110** and **130**, phase control section **140** and mirrors **120** and **150**. An example of an optically passive section is the portion of waveguide **105** proximal to output facet **195**.

According to the invention, at least a portion of laser **180** and optical amplifier **190** share a common waveguide **105**. Different portions of the common waveguide may extend through optically active or passive regions. A common waveguide for the laser and optical amplifier enables the output from the laser to be directly coupled into the amplifier.

In the embodiment of FIG. **1**A, amplifier **190** is external to the resonant cavity of laser **180** formed by mirrors **120** and **150**. Moreover, amplifier gain section **110** is separately controllable from the laser and is adjustable to increase or decrease the light intensity and output power. The SGBDR laser elements may be controlled separately from the amplifier to tune the laser frequency and otherwise control the input to the optical amplifier. By this arrangement of elements, power amplification and tuning functions are substantially uncoupled.

In the embodiment of FIG. **1**A, optical amplifier **190** has an active section and a passive section. The active section, amplifier gain section **110**, is substantially straight. The passive section of waveguide **105** is curved and intersects output facet **195** at an oblique angle. Both waveguide curvature and the oblique intersection with the output facet act to prevent reflections at the output facet from coupling back into the optical amplifier **190** and laser **180**.

FIG. **1**B shows a longitudinal cross section of a laser assembly **100** of FIG. **1**A. In FIG. **1**B, laser assembly **100**, waveguide **105**, amplifier gain section **110**, front resonator mirror **120**, laser gain section **130**, laser phase control section **140**, back mirror **150** and electrical contact **160**, epitaxial structure **170**, laser **180**, optical amplifier **190**, output facet **195**, p type semiconductor layer **125**, n-type semiconductor layer **115**, mirror sampling period **135**, offset quantum wells **145** and stop etch layer **155** are shown.

In FIG. **1**B waveguide **105** is formed between p-type and n-type semiconductor layers **125** and **115**, respectively. Mirrors **120** and **150** are formed by sample gratings etched in waveguide **105** with sampling period **135**, as is well-understood in the art.

FIG. **1**B illustrates the structure resulting from an offset quantum well technique for optically active and passive section formation. According to the offset quantum well technique, the optically active sections have multiple quantum well layers **145** grown in a region offset from waveguide **105**. The multiple quantum well layers are separated from the waveguide by a thin stop etch layer **155**. Removal of quantum wells, by etching for example, forms optically passive sections.

FIGS. **2**A–**2**C illustrate cross-sectional structures over a portion of laser assembly **100** (see FIG. **1**) resulting from different techniques for forming optically active and passive sections and their junctions. FIG. **2**A illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. **1**) resulting from a selected area regrowth technique. The selected area regrowth technique uses a dielectric mask to selectively control the growth rate and composition over different areas of the epitaxial structure. Thus, the material's bandgap can be shifted in certain sections making the material in that section passive or non-absorbing at desired wavelengths. In FIG. **2**A, optically passive section **210**, optically active section **220**, bandgap-shifted quantum wells **230**, active section quantum wells **240**, and waveguide **105** (see FIGS. **1**A–**1**B) are shown. In FIG. **2**A, different portions of waveguide **105** are optically active or passive due to bandgap-shifting of the quantum wells within the waveguide.

FIG. **2**B illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. **1**) resulting from a selected area disordering technique for forming optically active and passive sections. The selected area disordering technique uses a dielectric cap or ion implantation to introduce vacancies which can be diffused through an active region to disorder the quantum wells by intermixing them. This disordering shifts quantum well bandgaps, creating optically passive waveguide sections.

In FIG. **2**B, optically passive section **210**, optically active section **220**, disordered wells **250**, active section multiple quantum wells **260**, and waveguide **105** (see FIGS. **1**A–**1**B) are shown. In FIG. **2**B, different portions of waveguide **105**, sections **210** and **220**, are optically active or passive due to the organization of the quantum wells within the waveguide material.

FIG. **2**C illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. **1**) resulting from a butt joint regrowth technique for forming optically active and passive sections. According to the butt joint regrowth technique, the entire waveguide is etched away in optically passive sections and an optically passive waveguide is grown again. The newly grown portion of the waveguide is butted up against the active waveguide. In FIG. **2**B, optically passive section **210**, optically active section **220**, active, butt-joint interface **270**, passive waveguide section **275**, active waveguide section **285** and waveguide **105** (see FIGS. **1**A–**1**B) are shown. In FIG. **2**B, active waveguide section **285** and passive waveguide section **275** are separated by a distinct large gradient butt-joint interface **270** as a result of the etch removal process.

FIGS. **3**A–**3**D are plan views, illustrating different embodiments of optical amplifier **190** (see FIG. **1**). In FIGS. **3**A–**3**D optical amplifier **190**, waveguide **105**, epitaxial structure **170**, output facet **195**, active amplifier section **310**, passive amplifier section **320**, active-passive junction **330**, curved waveguide portion **340**, flared waveguide portions **350** and **355** and waveguide mode adapter **360** are shown.

In FIG. **3**A, optical amplifier **190** has an active amplifier section **310** combined with a passive amplifier section **320**, where the passive amplifier section includes curved

waveguide portion **340**. The curved waveguide portion intersects output facet **195** at an oblique angle. Both the waveguide curvature and oblique intersection significantly reduces the amount of light reflecting from the output facet back into the amplifier and laser. Active-passive junction **330** is preferably oblique to a centerline of waveguide **105** so that any reflections from this interface coupling back into the amplifier and laser will be reduced. However, alternate embodiments may have active-passive junction **330** substantially normal to a centerline of the waveguide.

FIG. **3**B shows an alternate embodiment where the amplifier active section has been segmented into a plurality of active sections in order to increase the amplifier output power and reduce a noise figure. In this embodiment shown in FIG. **3**B, the amplifier active section is segmented into two amplifier active sections **310** that may be independently controllable. Other embodiments have more than two amplifier active sections. This segmenting of the amplifier enables the use of different bias points for the different sections. Having a plurality of amplifier stages allows higher saturated output powers to be reached with better noise performance.

FIG. **3**C shows an alternate embodiment where a waveguide portion in the amplifier active section is flared, or tapered, to increase the saturated output power. Flared waveguide portion **350** increases the amplifier active volume as compared to the embodiment shown in FIG. **3**A and decreases the photon density. To accomplish this effectively without introducing significant fiber coupling difficulties it is preferable to use an adiabatic flare, wherein there is no energy transfer across optical modes over the flare to a wider waveguide cross-section. In a preferred embodiment, a second flared-down section **355** to a narrow waveguide cross-section is positioned in the amplifier optically passive section **320** since it is difficult to couple effectively from a wide waveguide into a single mode fiber at output facet **195**. In a preferred embodiment, such a flared-down portion is before a curved waveguide portion **340**, otherwise, higher order modes will be excited when curving the wide waveguide. In the embodiment shown in FIG. **3**C, active-passive junction **330** is angled so that any reflections from this interface coupling back into the amplifier and laser will be reduced.

FIG. **3**D shows another embodiment including a waveguide mode adapter. A waveguide mode adapter is preferred in many embodiments to enlarge the optical mode near output facet **195** so that it is more closely matched to the mode in an optical fiber that, as an element in a communications system, may carry the light away from the output facet. Including a waveguide mode adapter thus reduces the fiber coupling loss and increases the alignment tolerances between laser assembly **100** (see FIG. **1**) and an optical fiber of another system. An embodiment of a waveguide mode adapter includes a section of passive waveguide wherein the waveguide's cross sectional is varied to expand the waveguide optical mode in an adiabatic manner.

The foregoing description of a preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in this art. It is intended that the scope of the invention be defined by the following claims and their equivalents.

What is claimed is:

1. A diode laser assembly, comprising:

substrate;

an epitaxal structure formed on the substrate;

a laser formed in the epitaxial structure, the laser including first and second reflectors, a gain section and a phase section, the gain section and the phase section each being positioned between the first and second reflectors to produce a tunable laser output therefrom; and

an amplifier formed in the epitaxial structure, at least a portion of the laser and amplifier sharing a common waveguide, the tunable laser output being coupled to the amplifier along the common waveguide, and the amplifier generating an optical signal in response to the coupled tunable laser output, wherein at least a portion of the waveguide is curved to reduce reflection from an output facet.

2. The laser assembly of claim **1** wherein the common waveguide has non-uniform optical properties along its centerline.

3. The laser assembly of claim **1** wherein the common waveguide has non-uniform cross-sectional area along its centerline.

4. The laser assembly of claim **1** wherein the common waveguide has non-uniform curvature along its centerline.

5. The laser assembly of claim **1** wherein the common waveguide has non-uniform optical properties normal to its centerline.

6. The assembly of claim **1**, wherein the amplifier includes at least one active region and at least one passive region.

7. The assembly of claim **6**, wherein the waveguide extends through an active region and a passive region.

8. The assembly of claim **7**, wherein a portion of the waveguide in the amplifier is curved.

9. The assembly of claim **7**, wherein at least a portion of the waveguide in a passive region of the amplifier is curved.

10. The assembly of claim **7**, wherein a portion of the waveguide in the amplifier is curved and the amplifier includes a flared waveguide section.

11. The assembly of claim **7**, wherein an interface between the active region and the passive region is oblique to a centerline of the waveguide.

12. The assembly of claim **7**, wherein an interface between the active region and the passive region is substantially normal to a centerline of the waveguide.

13. The assembly of claim **7**, wherein an end of the waveguide in the amplifier terminates at an oblique angle to an output facet.

14. The assembly of claim **6**, wherein the waveguide includes a waveguide mode adapter.

15. The assembly of claim **6**, wherein the first active region has a oblique distal face.

16. The assembly of claim **1**, wherein the laser has a multi-active region gain medium.

17. The assembly of claim **1**, wherein the epitaxial structure has areas of differing optical properties.

18. The assembly of claim **1**, wherein the waveguide includes active section.

19. The assembly of claim **18**, wherein the active section of the waveguide is positioned in the first active section of the amplifier.

20. The assembly of claim **18**, where the active section of the waveguide is positioned in the second active section of the amplifier.

21. The assembly of claim **1**, wherein at least a portion of the waveguide is non-parallel to an axis of the laser's cavity.

22. The assembly of claim **1**, wherein the amplifier includes a plurality of independently controllable active regions.

23. The assembly of claim **22**, wherein a first and a second active region are separated by a passive region.

24. The assembly of claim **23**, wherein the first active region has a oblique distal face.

25. The assembly of claim **23**, wherein the second active region has an oblique proximal face.

26. The assembly of claim **23**, wherein the oblique distal face of the first active region is parallel to the oblique proximal face of the second active region.

27. The assembly of claim **23**, wherein the second active region has a oblique distal face.

28. The assembly of claim **27**, wherein the proximal face and the distal face of the second region are parallel.

29. The assembly of claim **1**, wherein a width of the laser output is independent of a width of the waveguide at an output of the amplifier.

30. The assembly of claim **1**, wherein the laser includes a mode selection element.

31. The assembly of claim **30**, wherein the mode selection element is a controllable phase shifting element.

32. The assembly of claim **1**, wherein the at least one of the first and second reflectors is tunable.

33. The assembly of claim **32**, wherein at least one of the first and second reflectors is a distributed reflector.

34. The assembly of claim **32**, wherein both of the first and second reflectors are distributed reflectors.

35. The assembly of claim **32**, wherein at least one of the first and second reflectors is a distributed Bragg reflector.

36. The assembly of claim **32**, wherein each of the first and second reflectors is a distributed Bragg reflector.

37. The assembly of claim **32**, wherein a maximum reflectivity of at least one of the first and second reflectors is tunable.

38. The assembly of claim **32**, wherein a maximum reflectivity of each of the first and second reflectors is tunable.

39. The assembly of claim **32**, wherein the maximum reflectivities of each of the first and second reflectors are tunable relative to each other.

40. The assembly of claim **32**, wherein the laser includes an attenuator and at least one amplifier positioned outside of the laser.

41. The assembly of claim **32**, wherein the laser includes a controllable amplifier positioned outside of the laser.

42. The assembly of claim **32**, wherein the laser includes a controllable attenuator positioned outside of the laser.

43. The assembly of claim **1**, wherein at least a portion of the waveguide is flared.

44. The assembly of claim **43**, wherein a flared portion of the waveguide is in an active region.

45. The assembly of claim **43**, wherein a flared portion of the waveguide is in a passive region.

46. The assembly of claim **1**, wherein the optical signal is tunable within a range of at least 15 nm.

47. A diode laser assembly, comprising:

a first semiconductor layer in an epitaxial structure;

a second semiconductor layer formed in the epitaxial structure, the first and second semiconductor layers having different dopings;

a waveguide layer formed between the first and second semiconductor layers, the first waveguide layer including a waveguide, a first reflector and a second reflector;

an optically active medium disposed between the first and second reflectors, the first and second reflectors defining a laser cavity and producing a tunable laser output; and

an amplifier formed in the epitaxial structure, wherein the laser cavity and the amplifier are optically aligned, the tunable laser output being coupled into the amplifier along the waveguide, and the amplifier generating an optical signal in response to the coupled tunable laser output, wherein at least a portion of the waveguide is curved to reduce reflections from an output facet.

48. The assembly of claim **47**, wherein a distal portion of the waveguide in the amplifier is curved.

49. The assembly of claim **47**, wherein a distal end of the waveguide in the amplifier terminates at an oblique angle to an output facet.

50. The assembly of claim **47**, wherein at least a portion of the waveguide is non-parallel to an axis of the laser cavity.

51. The assembly of claim **47**, wherein at least a portion of the waveguide is flared.

52. The assembly of claim **47**, wherein the waveguide includes an active section.

53. The assembly of claim **52**, wherein the active section of the waveguide is positioned in the first active section of the amplifier.

54. The assembly of claim **52**, wherein the active section of the waveguide is positioned in the second active section of the amplifier.

55. The assembly of claim **47**, wherein the amplifier includes a first active region and a passive region.

56. The assembly of claim **55**, wherein the amplifier includes a second active region.

57. The assembly of claim **55**, wherein the first and second active regions are separated by a passive region.

58. The assembly of claim **57**, wherein the first active region has an oblique distal face.

59. The assembly of claim **58**, wherein the second active region has au oblique proximal face.

60. The assembly of claim **59**, wherein the oblique distal face of the first active region is parallel to the oblique proximal face of the second active region.

61. The assembly of clam **59**, wherein the second active region has an oblique distal face.

62. The assembly of claim **61**, wherein the proximal face and the distal face of the second region are parallel.

63. The assembly of claim **55**, wherein the waveguide extends through at least a portion of the amplifier.

64. The assembly of claim **55**, wherein the first active region has an oblique distal face.

65. The assembly of claim **55**, wherein the waveguide extends through the first active region and the passive region.

66. The assembly of claim **55**, wherein the waveguide includes a mode adapter.

67. The assembly of claim **47**, wherein at least one of the first and second reflectors is tunable.

68. The assembly of claim **67**, wherein both of the first and second reflectors is a distributed reflector.

69. The assembly of claim **67**, wherein at least one of the first and second reflectors is a distributed Bragg reflector.

70. The assembly of claim **67**, wherein each of the first and second reflectors is a distributed Bragg reflector.

71. The assembly of claim **67**, wherein a maximum reflectivity of at least one of the first and second reflectors is tunable.

72. The assembly of claim **67**, wherein a maximum reflectivity of each of the first and second reflectors is tunable.

73. The assembly of claim **67**, wherein the maximum reflectivities of each of the first and second reflectors are tunable relative to each other.

74. The assembly of claim **67**, wherein the laser includes a controllable amplifier positioned outside of the laser.

75. The assembly of claim **67**, wherein the laser includes a controllable attenuator positioned outside of the laser.

76. The assembly of claim **67**, wherein the laser includes an attenuator and at least one amplifier positioned outside of the resonant cavity.

77. The assembly of claim **67**, wherein at least one of the first and second reflectors is a distributed reflector.

78. The assembly of claim **47**, wherein the laser includes a mode selection element.

79. The assembly of claim **78**, wherein the mode selection element is a controllable phase shifting element.

80. The assembly of claim **47**, wherein the optical signal is tunable within a range of at least 15 nm.

81. The assembly of claim **47**, wherein a width of the tunable laser output is independent of a width of the waveguide at an output of the amplifier.

82. The assembly of claim **47**, wherein the epitaxial structure has areas of differing optical properties.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,658,035 B1 Page 1 of 1
DATED : December 2, 2003
INVENTOR(S) : Thomas Beck Mason, Gregory Fish and Larry Coldren

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 6,
Line 17, "reflection" should read -- reflections --.

Column 7,
Line 23, delete "the" (second occurrence).

Column 8,
Line 34, "au" should read -- an --.

Signed and Sealed this

Sixteenth Day of March, 2004

Jon W. Dudas

JON W. DUDAS
Acting Director of the United States Patent and Trademark Office

EXHIBIT 2

US006654400B1

(12) **United States Patent**
Mason et al.

(10) **Patent No.: US 6,654,400 B1**
(45) **Date of Patent: Nov. 25, 2003**

(54) **METHOD OF MAKING A TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL AMPLIFIER**

(75) Inventors: **Thomas Beck Mason**, Middletown, NJ (US); **Gregory Fish**, Santa Barbara, CA (US); **Larry Coldren**, Santa Barbara, CA (US)

(73) Assignee: **Agility Communications, Inc.**, Goleta, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 302 days.

(21) Appl. No.: **09/614,224**

(22) Filed: **Jul. 12, 2000**

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/614,377, filed on Jul. 12, 2000, now Pat. No. 6,580,739, and a continuation-in-part of application No. 09/614,665, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,895, filed on Jul. 12, 2000, now Pat. No. 6,349,106, and a continuation-in-part of application No. 09/614,378, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,376, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,674, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,195, filed on Jul. 12, 2000, now Pat. No. 6,574,259, and a continuation-in-part of application No. 09/614,375, filed on Jul. 12, 2000.

(60) Provisional application No. 60/152,072, filed on Sep. 2, 1999, provisional application No. 60/152,049, filed on Sep. 2, 1999, and provisional application No. 60/152,038, filed on Sep. 2, 1999.

(51) **Int. Cl.**[7] **H01S 5/026**
(52) **U.S. Cl.** **372/50**; 372/20; 438/22
(58) **Field of Search** 372/20, 50; 438/34, 438/22

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,896,325	A	*	1/1990	Coldren	372/20
5,084,894	A	*	1/1992	Yamamoto	372/50
5,088,105	A		2/1992	Scifres et al.	372/92
5,145,792	A	*	9/1992	Hirata	438/36
5,253,314	A	*	10/1993	Alferness et al.	385/40
5,274,649	A	*	12/1993	Hirayama et al.	372/20
5,325,392	A	*	6/1994	Tohmori et al.	372/96
5,396,511	A	*	3/1995	Nakatsuka et al.	372/43
5,452,118	A	*	9/1995	Maruska	359/191
5,479,539	A		12/1995	Goldsmith et al.	385/14
5,525,541	A		6/1996	Krauz et al.	438/28
5,539,571	A	*	7/1996	Welch et al.	359/344
5,625,636	A		4/1997	Bryan et al.	372/50
5,674,778	A		10/1997	Lee et al.	438/24
5,715,268	A		2/1998	Lang et al.	372/50
5,742,045	A		4/1998	Parker et al.	250/214 A
5,838,714	A	*	11/1998	Delorme	372/96
6,031,851	A	*	2/2000	Shimizu et al.	372/18
6,208,454	B1	*	3/2001	Koren et al.	359/326
6,349,106	B1	*	2/2002	Coldren	372/50

FOREIGN PATENT DOCUMENTS

EP	1 539 028	1/1979	H01S/3/02
EP	0 620 475 A1	3/1994	G02F/1/313

OTHER PUBLICATIONS

Bar–Chaim, N. et al., "Monolithic Optoelectronic Integration of a GaAIAs Laser, a Field–Effect Transistor, and a Photodiode", *Applied Physics Letters, US, American Institute of Physics*, May 15, 1984, vol. 44, No. 10, pp. 941–943.

(List continued on next page.)

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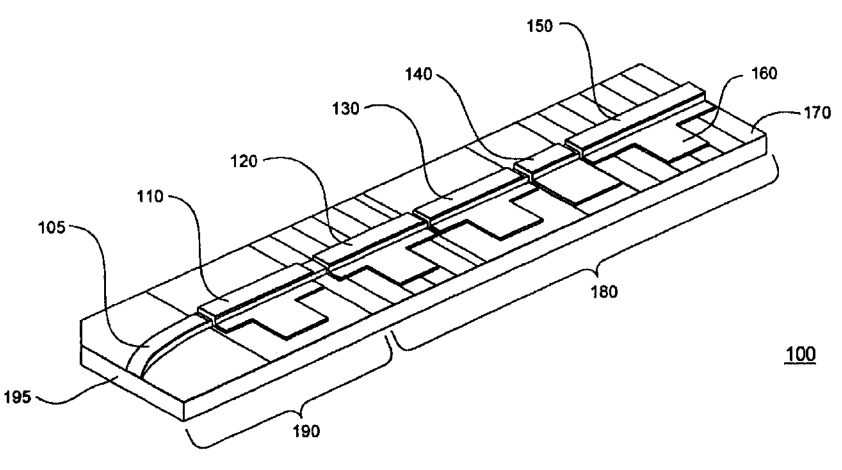
(74) *Attorney, Agent, or Firm*—Gates & Cooper LLP

(57) **ABSTRACT**

A method of making a diode laser assembly provides a substrate. An epitaxial structure is formed on the substrate. Different areas of the epitaxial structure have different optical properties. A laser, a modulator and a coupler are formed in the epitaxial structure.

76 Claims, 7 Drawing Sheets



OTHER PUBLICATIONS

Koch, T.L., "Semiconductor Photonic Integrated Circuits", *IEEE Journal of Quantum Electronics*, Mar. 27, 1991, No. 3, pp. 641–653.

Byoung–Sung, K. et al., "Dynamic Analysis of Widely Tunable Laser Diodes Integrated with Sampled–and–Chirped–Grating Distributed Bragg Reflectors and an Electroabsorption Modulator", *IEICE Trans Electron*, Aug. 1998, vol. E81–C, No. 8, pp. 1342–1349.

San–Liang, L. et al., "Sampled Grating DBR Laser Arrays with Adjustable 0.8/1.6–nm Wavelength Spacing", *IEEE Photonics Technology Letters*, Aug. 1999, vol. 11, No. 8, pp. 955–957.

Jayaraman, V. et al., "Theory, Design, and Performance of Extended Tuning Range Semiconductor Lasers with Sampled Gratings", *IEEE Journal of Quantum Electronics*, Jun. 29, 1993, vol. 29, No. 6, pp. 1824–1834.

* cited by examiner

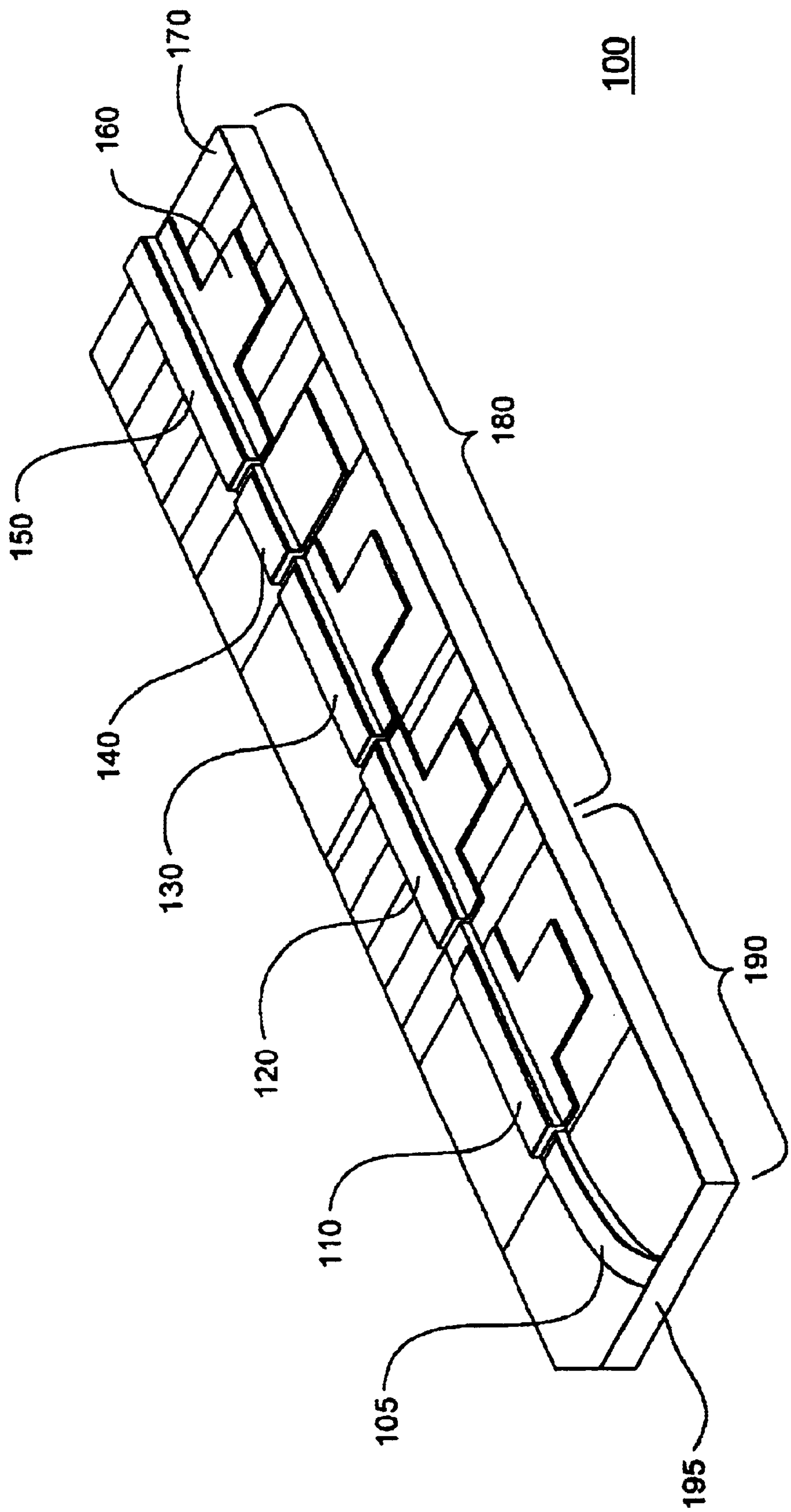


FIG. 1A

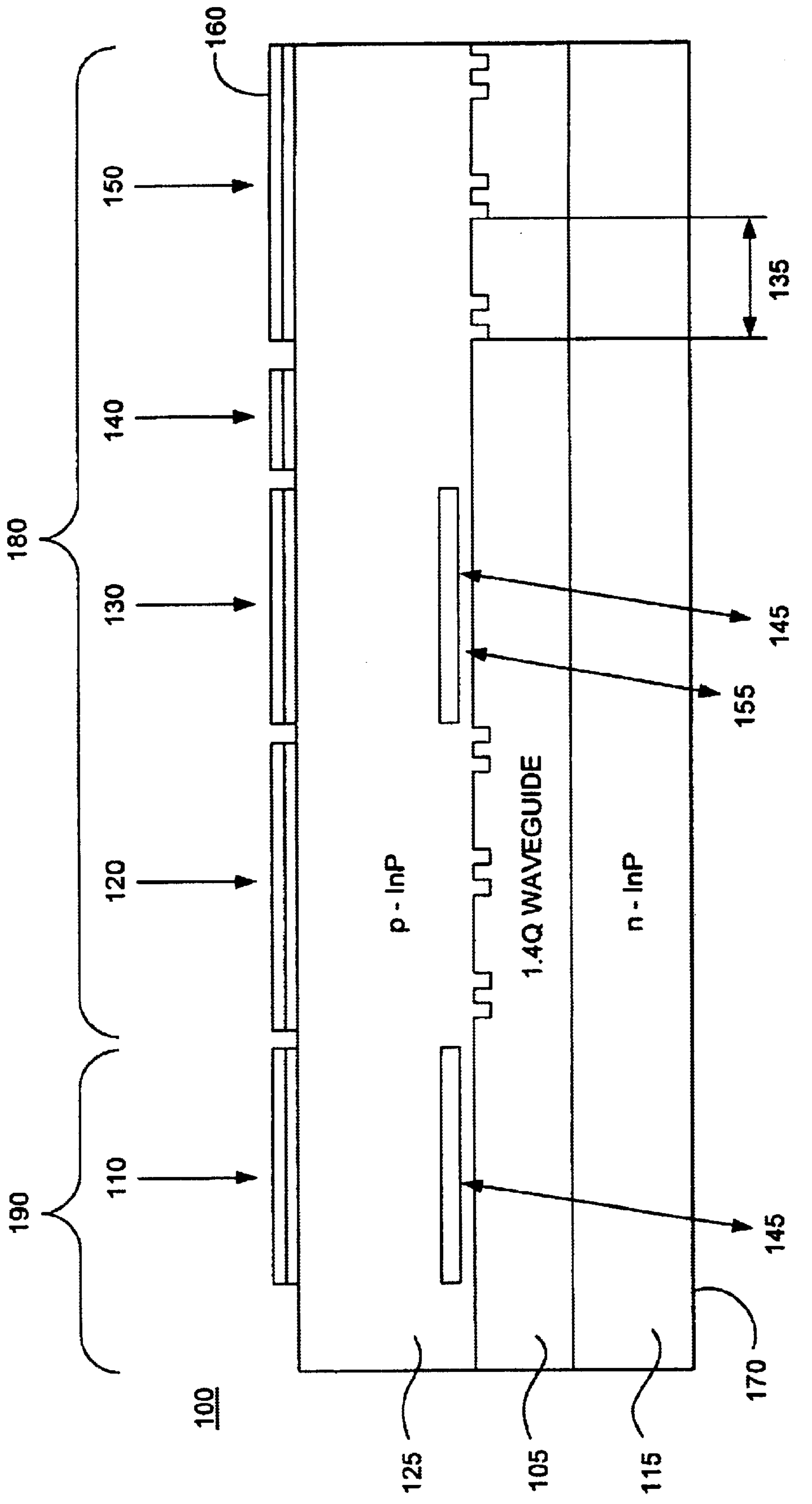

160
150
140
130
120
110
180
190
135
145
155
145
p - InP
1.4Q WAVEGUIDE
n - InP
100
125
105
115
170

FIG. 1B

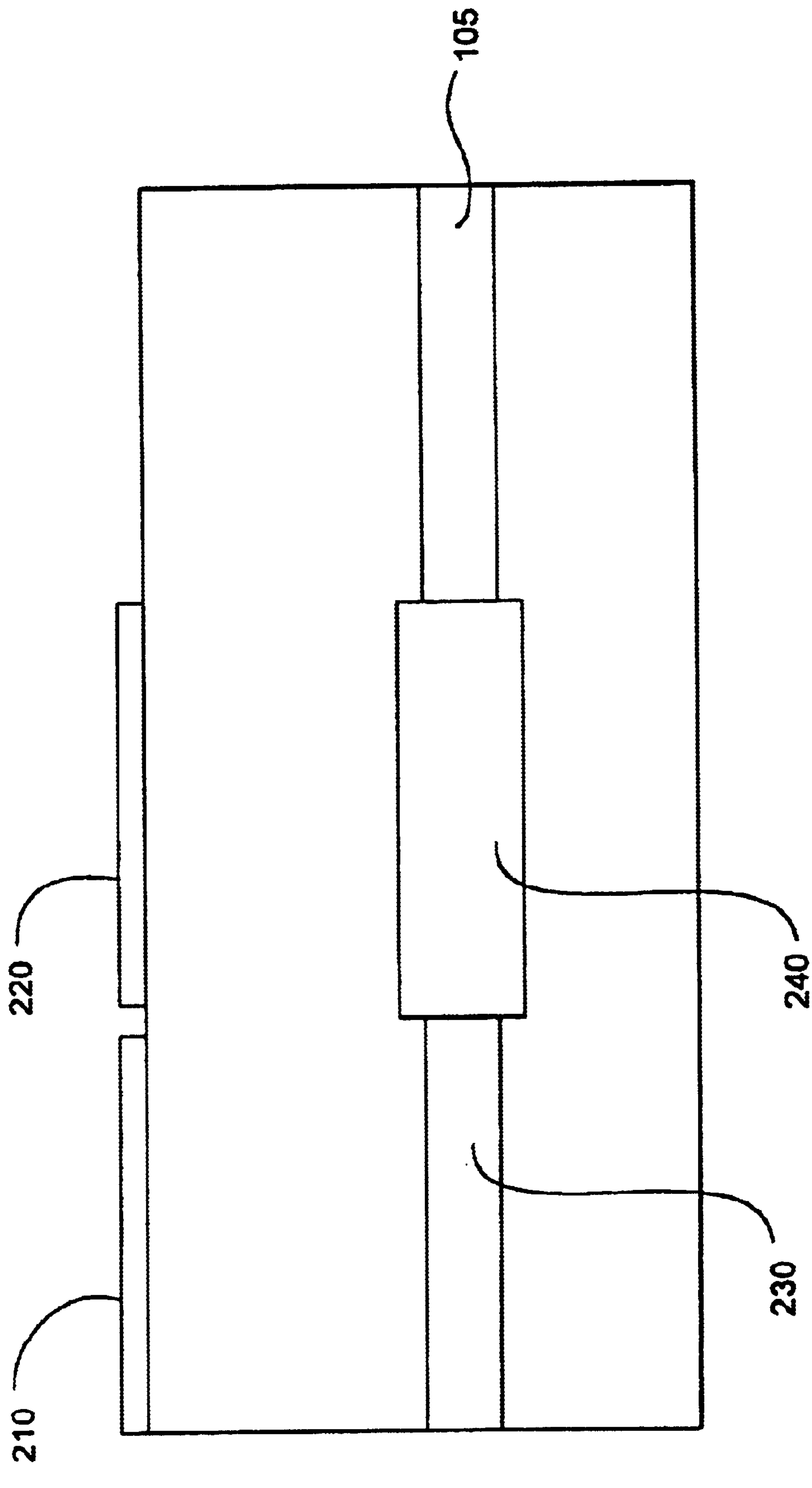


FIG. 2A

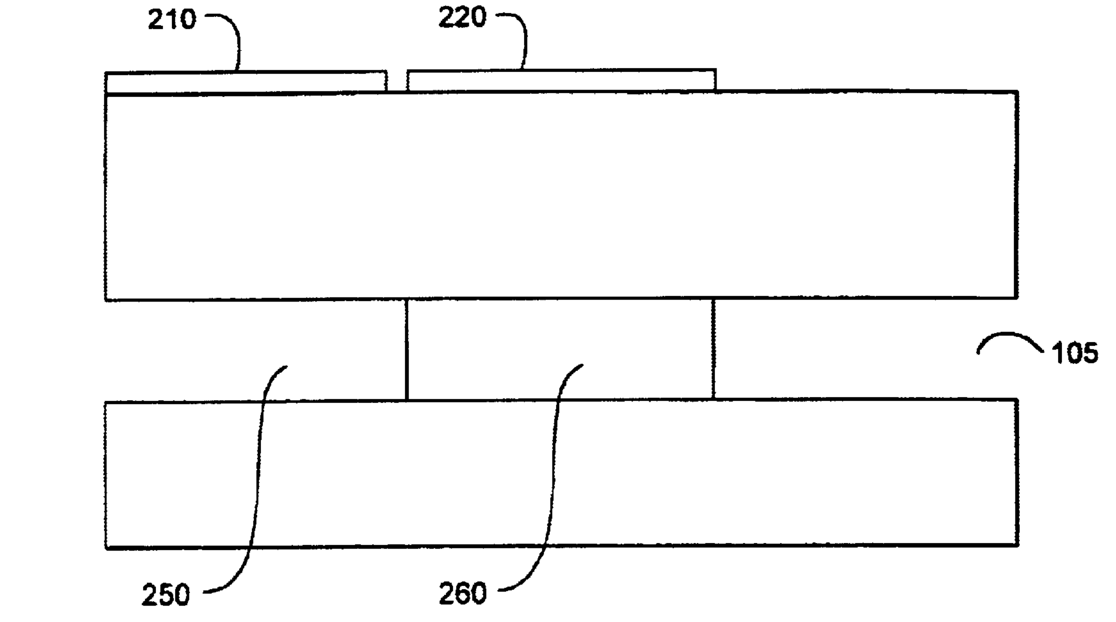


FIG. 2B

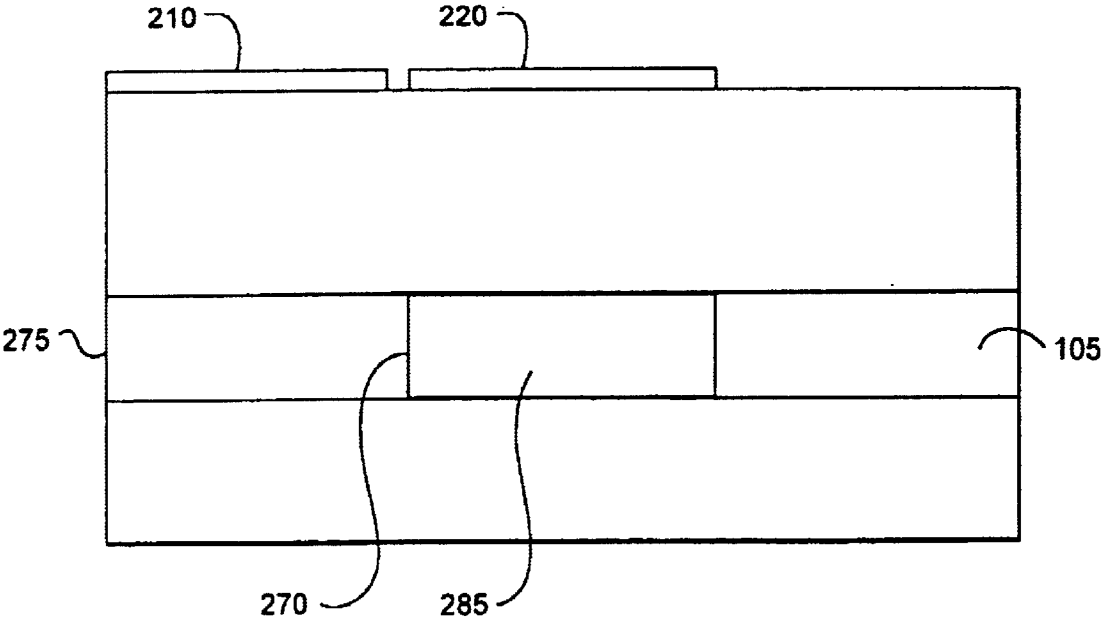


FIG. 2C

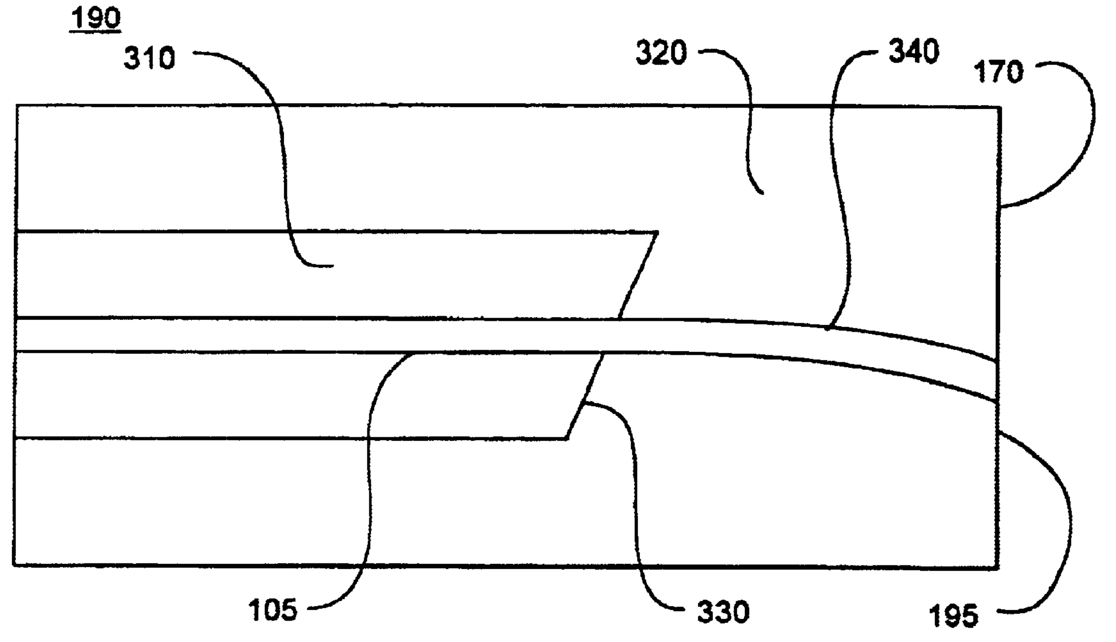


FIG. 3A

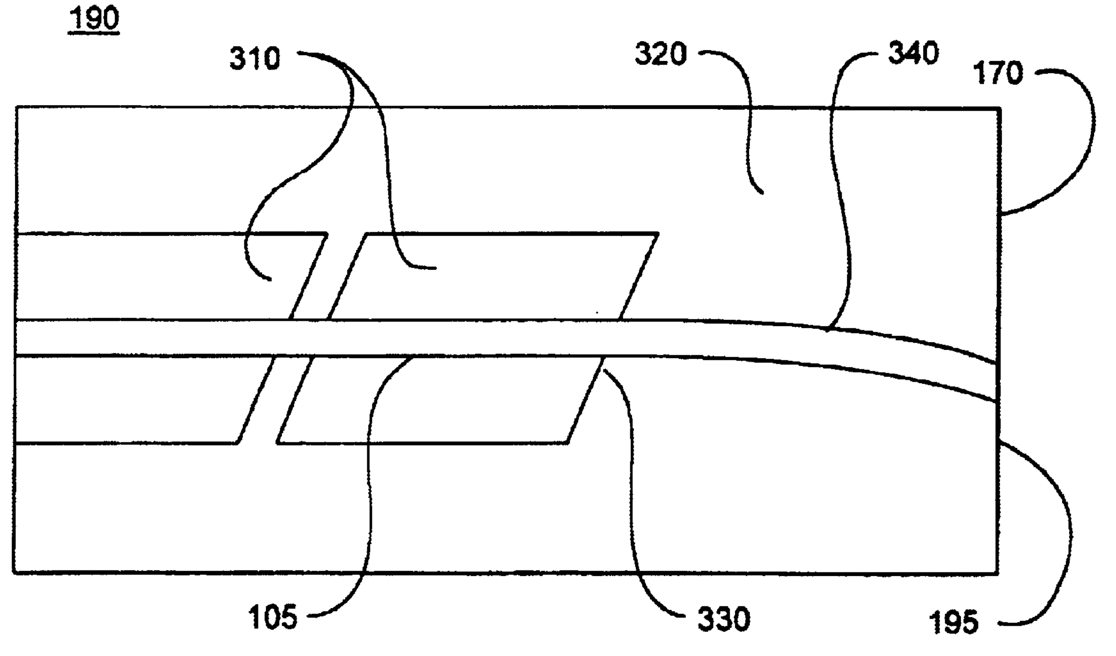


FIG. 3B

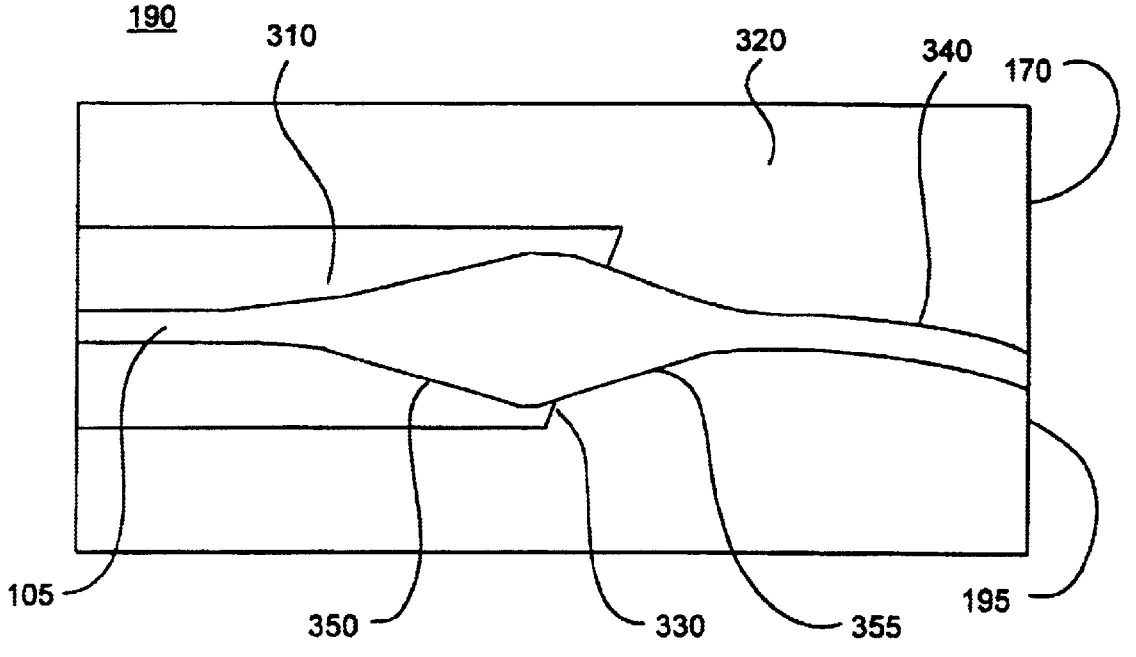


FIG. 3C

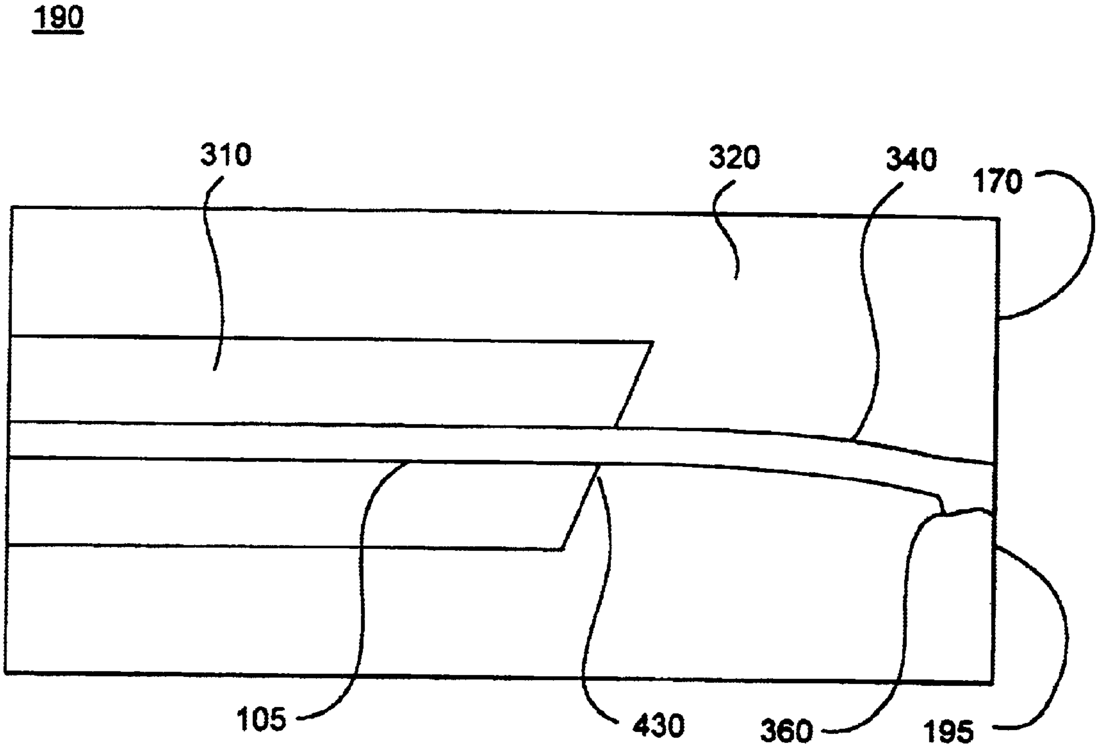


FIG. 3D

METHOD OF MAKING A TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL AMPLIFIER

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part and claims the benefit of priority of U.S. Provisional Application Serial No. 60/152,072, filed Sep. 2, 1999, U.S. Provisional Application Serial No. 60/152,049, filed Sep. 2, 1999, U.S. Provisional Application Serial No. 60/152,038, filed Sep. 2, 1999, which applications are fully incorporated by reference herein. This application is also a continuation-in-part of U.S. Ser. Nos. 09/614/377, now U.S. Pat. No. 6,580,739 09/614,895 (now U.S. Pat. No. 6,349,106, issued Feb. 19, 2002), Ser. Nos. 09/614,674, 09/614,378, 09/614,376, 09/614,195, now U.S. Pat. No. 6,574,259 09/614,375 and 09/614,665, filed on the same date Jul. 12, 2000 which applications are fully incorporated by reference herein.

FIELD OF THE INVENTION

This invention relates generally to laser assemblies, and more particularly to a widely tunable laser assembly with an integrated optical amplifier.

BRIEF DESCRIPTION OF THE RELATED ART

Thin fibers of optical materials transmit light across a very broad frequency bandwidth and therefore communications data from a light source may be transmitted over such fibers over broad frequency ranges. At any particular frequency, a laser source must have high output power, narrow laser linewidth and good transmission performance through great distances of optical fiber.

In higher bandwidth communications systems, where many frequencies of laser light are transmitted along a fiber, there may be one or several laser sources. While a tunable laser source would be preferred, higher data capacity systems presently use multiple laser sources operating on different frequency channels to cover the wide fiber transmission bandwidth. This is the case since appropriate laser sources are presently incapable of rapid, electronic frequency tuning without attendant deterioration of other significant figures-of-merit.

For example, at a fixed frequency, sampled grating distributed Bragg reflector (SGDBR) lasers have the high output power, narrow laser linewidth and good transmission performance necessary for an optical data network. While some SGDBR lasers can be rapidly tuned over more than 100 different transmission channels, two problems nevertheless prevent these devices from being employed in fiber optic communication systems. The most significant problem is the significant absorption of the mirror material. The resulting large cavity losses act to make the laser output power insufficient for the requirements of a present-day communications system. A second problem is that the output power and frequency tuning are dependent on each other. This coupling results in inadequate controllability for a present-day communications system.

What is needed, instead, is a device with a combination of sufficiently high output power for a high-bandwidth optical communications network and with frequency tuning controllability substantially independent of output power controllability.

SUMMARY

Accordingly, an object of the present invention is to provide an integrated laser assembly that includes a tunable solid state laser and optical amplifier where all of the elements are fabricated in a common epitaxial layer structure.

Another object of the present invention is to provide an integrated laser assembly that includes a tunable solid state laser and optical amplifier with an output mode conditioned for transmission in an optical fiber.

Another object of the present invention is to provide an integrated laser assembly that includes a tunable laser and optical amplifier reducing optical feedback from the amplifier to the laser.

A further object of the present invention is to provide a tunable, integrated laser assembly where laser frequency control and output power control are substantially independent.

These and other objects of the present invention are achieved in a laser assembly that includes an epitaxial structure formed on a substrate. A tunable laser resonator and a separately controllable optical amplifier are formed in the common epitaxial structure. The amplifier is positioned outside of the laser resonator cavity to receive and adjust an output received from the laser, however, at least a portion of the laser and amplifier share a common waveguide.

In different embodiments of the present invention, properties of the common waveguide such as optical properties, or centerline curvature or cross-sectional are nonuniform along the waveguide centerline or non-uniform across a normal to the centerline.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1**A is a block diagram of a laser assembly that illustrates different functional elements of a laser assembly.

FIG. **1**B is a cross-sectional view of one embodiment of a widely tunable laser assembly of the present invention and the integration of materials with differing optical properties by an offset quantum well technique.

FIG. **2**A is a cross-sectional view of one embodiment of an amplifier illustrating several layer structures and the integration of two materials with differing optical properties by a selected area growth technique.

FIG. **2**B is a cross-sectional view of the FIG. **2** assembly illustrating one embodiment for the integration of materials with differing optical properties by a disordered well technique.

FIG. **2**C is a cross-sectional view of one embodiment of an amplifier illustrating one embodiment for the integration of several different band gap materials by a butt joint regrowth technique.

FIG. **3**A is a cross-sectional view of one embodiment of the FIG. **1** optical amplifier element where a portion of the waveguide is curved and an interface between an active and a passive section is oblique.

FIG. **3**B is a cross-sectional view of one embodiment of the FIG. **1** optical amplifier element where the amplifier includes a plurality of gain sections.

FIG. **3**C is a cross-sectional view of one embodiment of the FIG. **1** optical amplifier element where the amplifier includes a flared waveguide.

FIG. **3**D is a cross-sectional view of one embodiment of the FIG. **1** optical amplifier element where the amplifier includes a waveguide mode adapter.

DETAILED DESCRIPTION

FIG. **1**A shows a schematic of an embodiment of the invention. In FIG. **1**A, laser assembly **100**, waveguide **105**,

amplifier gain section **110**, front resonator mirror **120**, laser gain section **130**, laser phase control section **140**, back mirror **150** and electrical contact **160**, epitaxial structure **170**, laser **180**, optical amplifier **190** and output facet **195** are shown.

In FIG. **1**A, laser assembly **100** comprises an integration of a laser and an optical amplifier, with the optical amplifier located external to the laser cavity. Front resonator mirror **120**, laser gain section **130**, laser phase control section **140**, and back mirror **150** form a SGDBR-type laser **180** in epitaxial structure **170**. The front and back mirrors define a laser cavity. Amplifier gain section **110** and a portion of waveguide **105** define optical amplifier **190**.

As shown in FIG. **1**A, despite being external to the laser cavity, the optical amplifier shares a common epitaxial structure **170** with the laser. Epitaxial structure **170** is formed on a substrate (not shown) by processes well-known in the art of semiconductor fabrication. By tailoring optical properties (such as band gap) of different portions of the epitaxial structure, both optically active and optically passive sections can be fabricated in a common structure. Examples of optically active sections of the embodiment shown in FIG. **1** are gain sections **110** and **130**, phase control section **140** and mirrors **120** and **150**. An example of an optically passive section is the portion of waveguide **105** proximal to output facet **195**.

According to the invention, at least a portion of laser **180** and optical amplifier **190** share a common waveguide **105**. Different portions of the common waveguide may extend through optically active or passive regions. A common waveguide for the laser and optical amplifier enables the output from the laser to be directly coupled into the amplifier.

In the embodiment of FIG. **1**A, amplifier **190** is external to the resonant cavity of laser **180** formed by mirrors **120** and **150**. Moreover, amplifier gain section **110** is separately controllable from the laser and is adjustable to increase or decrease the light intensity and output power. The SGBDR laser elements may be controlled separately from the amplifier to tune the laser frequency and otherwise control the input to the optical amplifier. By this arrangement of elements, power amplification and tuning functions are substantially uncoupled.

In the embodiment of FIG. **1**A, optical amplifier **190** has an active section and a passive section. The active section, amplifier gain section **110**, is substantially straight. The passive section of waveguide **105** is curved and intersects output facet **195** at an oblique angle. Both waveguide curvature and the oblique intersection with the output facet act to prevent reflections at the output facet from coupling back into the optical amplifier **190** and laser **180**.

FIG. **1**B shows a longitudinal cross section of a laser assembly **100** of FIG. **1**A. In FIG. **1**B, laser assembly **100**, waveguide **105**, amplifier gain section **110**, front resonator mirror **120**, laser gain section **130**, laser phase control section **140**, back mirror **150** and electrical contact **160**, epitaxial structure **170**, laser **180**, optical amplifier **190**, output facet **195**, p type semiconductor layer **125**, n-type semiconductor layer **115**, mirror sampling period **135**, offset quantum wells **145** and stop etch layer **155** are shown.

In FIG. **1**B waveguide **105** is formed between p-type and n-type semiconductor layers **125** and **115**, respectively. Mirrors **120** and **150** are formed by sample gratings etched in waveguide **105** with sampling period **135**, as is well-understood in the art.

FIG. **1**B illustrates the structure resulting from an offset quantum well technique for optically active and passive section formation. According to the offset quantum well technique, the optically active sections have multiple quantum well layers **145** grown in a region offset from waveguide **105**. The multiple quantum well layers are separated from the waveguide by a thin stop etch layer **155**. Removal of quantum wells, by etching for example, forms optically passive sections.

FIGS. **2**A–**2**C illustrate cross-sectional structures over a portion of laser assembly **100** (see FIG. **1**) resulting from different techniques for forming optically active and passive sections and their junctions. FIG. **2**A illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. **1**) resulting from a selected area regrowth technique. The selected area regrowth technique uses a dielectric mask to selectively control the growth rate and composition over different areas of the epitaxial structure. Thus, the material's bandgap can be shifted in certain sections making the material in that section passive or non-absorbing at desired wavelengths. In FIG. **2**A, optically passive section **210**, optically active section **220**, bandgap-shifted quantum wells **230**, active section quantum wells **240**, and waveguide **105** (see FIGS. **1**A–**1**B) are shown. In FIG. **2**A, different portions of waveguide **105** are optically active or passive due to bandgap-shifting of the quantum wells within the waveguide.

FIG. **2**B illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. **1**) resulting from a selected area disordering technique for forming optically active and passive sections. The selected area disordering technique uses a dielectric cap or ion implantation to introduce vacancies which can be diffused through an active region to disorder the quantum wells by intermixing them. This disordering shifts quantum well bandgaps, creating optically passive waveguide sections.

In FIG. **2**B, optically passive section **210**, optically active section **220**, disordered wells **250**, active section multiple quantum wells **260**, and waveguide **105** (see FIGS. **1**A–**1**B) are shown. In FIG. **2**B, different portions of waveguide **105**, sections **210** and **220**, are optically active or passive due to the organization of the quantum wells within the waveguide material.

FIG. **2**C illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. **1**) resulting from a butt joint regrowth technique for forming optically active and passive sections. According to the butt joint regrowth technique, the entire waveguide is etched away in optically passive sections and an optically passive waveguide is grown again. The newly grown portion of the waveguide is butted up against the active waveguide. In FIG. **2**B, optically passive section **210**, optically active section **220**, active, butt-joint interface **270**, passive waveguide section **275**, active waveguide section **285** and waveguide **105** (see FIGS. **1**A–**1**B) are shown. In FIG. **2**B, active waveguide section **285** and passive waveguide section **275** are separated by a distinct large gradient butt-joint interface **270** as a result of the etch removal process.

FIGS. **3**A–**3**D are plan views, illustrating different embodiments of optical amplifier **190** (see FIG. **1**). In FIGS. **3**A–**3**D optical amplifier **190**, waveguide **105**, epitaxial structure **170**, output facet **195**, active amplifier section **310**, passive amplifier section **320**, active-passive junction **330**, curved waveguide portion **340**, flared waveguide portions **350** and **355** and waveguide mode adapter **360** are shown.

In FIG. **3**A, optical amplifier **190** has an active amplifier section **310** combined with a passive amplifier section **320**, where the passive amplifier section includes curved

waveguide portion **340**. The curved waveguide portion intersects output facet **195** at an oblique angle. Both the waveguide curvature and oblique intersection significantly reduces the amount of light reflecting from the output facet back into the amplifier and laser. Active-passive junction **330** is preferably oblique to a centerline of waveguide **105** so that any reflections from this interface coupling back into the amplifier and laser will be reduced. However, alternate embodiments may have active-passive junction **330** substantially normal to a centerline of the waveguide.

FIG. **3**B shows an alternate embodiment where the amplifier active section has been segmented into a plurality of active sections in order to increase the amplifier output power and reduce a noise figure. In this embodiment shown in FIG. **3**B, the amplifier active section is segmented into two amplifier active sections **310** that may be independently controllable. Other embodiments have more than two amplifier active sections. This segmenting of the amplifier enables the use of different bias points for the different sections. Having a plurality of amplifier stages allows higher saturated output powers to be reached with better noise performance.

FIG. **3**C shows an alternate embodiment where a waveguide portion in the amplifier active section is flared, or tapered, to increase the saturated output power. Flared waveguide portion **350** increases the amplifier active volume as compared to the embodiment shown in FIG. **3**A and decreases the photon density. To accomplish this effectively without introducing significant fiber coupling difficulties it is preferable to use an adiabatic flare, wherein there is no energy transfer across optical modes over the flare to a wider waveguide cross-section. In a preferred embodiment, a second flared-down section **355** to a narrow waveguide cross-section is positioned in the amplifier optically passive section **320** since it is difficult to couple effectively from a wide waveguide into a single mode fiber at output facet **195**. In a preferred embodiment, such a flared-down portion is before a curved waveguide portion **340**, otherwise, higher order modes will be excited when curving the wide waveguide. In the embodiment shown in FIG. **3**C, active-passive junction **330** is angled so that any reflections from this interface coupling back into the amplifier and laser will be reduced.

FIG. **3**D shows another embodiment including a waveguide mode adapter. A waveguide mode adapter is preferred in many embodiments to enlarge the optical mode near output facet **195** so that it is more closely matched to the mode in an optical fiber that, as an element in a communications system, may carry the light away from the output facet. Including a waveguide mode adapter thus reduces the fiber coupling loss and increases the alignment tolerances between laser assembly **100** (see FIG. **1**) and an optical fiber of another system. An embodiment of a waveguide mode adapter includes a section of passive waveguide wherein the waveguide's cross sectional is varied to expand the waveguide optical mode in an adiabatic manner.

The foregoing description of a preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in this art. It is intended that the scope of the invention be defined by the following claims and their equivalents.

What is claimed is:

1. A method of making a diode laser assembly, comprising:

providing a substrate;

forming an epitaxial structure on the substrate, the editorial structure having optically active and optically inactive areas;

forming a laser in the epitaxial structure, the laser including first and second reflectors, a gain section and a phase action, the gain section and the phase section each being positioned between the first and second reflectors to produce a tunable laser output therefrom; and

forming an amplifier in the epitaxial structure, at least a portion of the laser and amplifier sharing a common waveguide, the tunable laser output being coupled to the amplifier along the common waveguide, and the amplifier generating an optical signal in response to the coupled tunable laser output, wherein at least a portion of the waveguide is curved to reduce reflections from an output facet.

2. The method of claim **1**, wherein the optically active areas of the epitaxial structure are formed using off-set quantum wells.

3. The method of claim **1**, wherein the optically inactive areas are formed by a selective area growth.

4. The method of claim **1**, wherein the optically inactive areas are formed by a selective area growth using a dielectric mask.

5. The method of claim **1**, wherein the optically inactive areas are formed by selective area disordering.

6. The method of claim **1**, wherein the optically inactive areas are formed by butt joint regrowth.

7. The method of claim **1**, wherein the optically inactive areas are formed with multiple quantum well layers grown on top of the waveguide layer.

8. The method of claim **1**, further comprising:

forming areas of different bandgaps in the epitaxial structure.

9. The method of claim **1**, further comprising:

bombarding at least a portion of the epitaxial structure with ions; and

tailoring a bandgap of at least a portion of the epitaxial structure to create the gain section of the laser.

10. The method of claim **9**, further comprising:

annealing at least a portion of the epitaxial structure to diffuse impurities and vacancies in a selected region of the epitaxial structure to determine the region's optical properties.

11. The method of claim **9**, wherein the ions have an energy no greater than about 200 eV.

12. The method of claim **1**, wherein the amplifier includes a first active region and a passive region.

13. The method of claim **12**, wherein the waveguide extends through at least a portion of the amplifier.

14. The method of claim **13**, wherein the waveguide extends through the first active region and the passive region.

15. The method of claim **14**, wherein a distal portion of the waveguide in the amplifier is curved.

16. The method of claim **14**, wherein a distal portion of the waveguide in the amplifier is curved and the amplifier includes a tapered section.

17. The method of claim **14**, wherein a distal end of the waveguide in the amplifier terminates at an oblique angle to in output facet.

18. The method of claim **12**, wherein the first active region has a tapered distal face.

19. The method of claim **12**, wherein the amplifier includes a second active region.

20. The method of claim **19**, wherein the waveguide includes an active section.

21. The method of claim **20**, wherein the active section of the waveguide is positioned in the second active section of the amplifier.

22. The method of claim **20**, wherein the active section of the waveguide is positioned in the first active section of the amplifier.

23. The method of claim **19**, wherein the first and second active regions are separated by a passive region.

24. The method of claim **23**, wherein the first active region has a tapered distal face.

25. The method of claim **24**, wherein the second active region has a tapered proximal face.

26. The method of claim **25**, wherein the second active region has a tapered distal face.

27. The method of claim **26**, wherein the proximal face and the distal face of the second region are parallel.

28. The method of claim **25**, wherein the tapered distal face of the first active region is parallel to the tapered proximal face of the second active region.

29. The method of claim **1**, wherein at least one of the first and second reflectors is a distributed Bragg reflector.

30. The method of claim **29**, wherein a maximum reflectivity of at least one of the first and second reflectors is tunable.

31. The method of claim **30**, wherein the maximum reflectivities of each of the first and second reflectors are tunable relative to each other.

32. The method of claim **1**, wherein at least a portion of the waveguide is non-parallel to an axis of the laser's cavity.

33. The method of claim **1**, wherein a width of the tunable laser output is independent of a width of the waveguide at an output of the amplifier.

34. The method of claim **1**, wherein at least a portion of the waveguide is flared-out in an active section of the amplifier and flared-in in a passive section of the amplifier.

35. The method of claim **1**, further comprising a waveguide mode adapter to enlarge an optical mode near the output facet so that it is more closely matched to the mode in an optical fiber that cries the light away from the output facet.

36. The method of claim **35**, wherein the waveguide mode adapter includes a section of passive waveguide and the waveguide's cross section is varied to expand the waveguide's optical mode in an adiabatic manner.

37. The method of claim **1**, wherein the optical signal is tunable within a range of at least 15 nm.

38. The method of claim **1**, wherein at least a portion of the waveguide is tapered.

39. A method of making a diode assembly, comprising:

providing a substrate;

forming a first semiconductor layer and a second semiconductor layer in an epitaxial structure having optically active and optically inactive areas, the first and second semiconductor layers having different dopings; and

forming a first waveguide layer between the first and second semiconductor layers, the first waveguide layer including a waveguide, a first reflector and a second reflector;

forming an optically active medium disposed between the first and second reflectors, the first and second reflectors defining a laser cavity and producing a tunable laser output; and

forming an amplifier in the epitaxial structure, wherein the laser cavity and the amplifier are optically aligned, the tunable laser output being coupled into the amplifier along the waveguide, and the amplifier generating an optical signal in response to the coupled tunable laser output, wherein at least a portion of the waveguide is curved to reduce reflections from an output facet.

40. The method of claim **39**, further comprising:

forming areas of different bandgaps in the epitaxial structure.

41. The method of claim **39**, further comprising:

bombarding at least a portion of the epitaxial structure with ions; and

tailoring a bandgap of at least a portion of the epitaxial structure to create a gain medium of the laser.

42. The method of claim **41**, further comprising:

annealing at least a portion of the epitaxial structure to diffuse impurities and vacancies in a selected region of the epitaxial structure to determine the region's optical properties.

43. The method of claim **41**, wherein the ions have an energy no greater than about 200 eV.

44. The method of claim **39**, wherein the amplifier includes a first active region and a passive region.

45. The method of claim **44**, wherein the waveguide layer includes a waveguide that extends through at least a portion of the amplifier.

46. The method of claim **45**, wherein the waveguide extends through the first active region and the passive region.

47. The method of claim **46**, wherein a distal portion of the waveguide in the amplifier is curved.

48. The method of claim **46**, wherein a distal portion of the waveguide in the amplifier is curved and the amplifier includes a tapered section.

49. The method of claim **46**, wherein a distal end of the waveguide in the amplifier terminates at an oblique angle to an output facet.

50. The method of claim **45**, wherein at least a portion of the waveguide is tapered.

51. The method of claim **44**, wherein the amplifier includes a second active region.

52. The method of claim **51**, wherein the waveguide includes an active section.

53. The method of claim **52**, wherein the active section of the waveguide is positioned in the second active section of the amplifier.

54. The method of claim **52**, wherein the active section of the waveguide is positioned in the first active section of the amplifier.

55. The method of claim **51**, wherein the first and second active regions are separated by a passive region.

56. The method of claim **55**, wherein the first active region has a tapered distal face.

57. The method of claim **56**, wherein the second active region has a tapered proximal face.

58. The method of claim **57**, wherein the second active region has a tapered distal face.

59. The method of claim **58**, wherein the proximal face and the distal face of the second region are parallel.

60. The method of claim **57**, wherein the tapered distal face of the first active region is parallel to the tapered proximal face of the second active region.

61. The method of claim **44**, wherein the first active region has a tapered distal face.

62. The method of claim **39**, wherein at least one of the first and second reflectors is a distributed Bragg reflector.

63. The method of claim **62**, wherein a maximum reflectivity of at least one of the first and second reflectors is tunable.

64. The method of claim **63**, wherein the maximum reflectivities of each of the first and second reflectors are tunable relative to each other.

65. The method of claim **39**, wherein at least a portion of the waveguide is non-parallel to an axis of the laser cavity.

66. The method of claim **39**, wherein a width of the tunable laser output is independent of a width of the waveguide at an output of the amplifier.

67. The method of claim **39**, wherein at least a portion of the waveguide is flared-out in an active section of the amplifier and flared-in in a passive section of the amplifier.

68. The method of claim **39**, further comprising a waveguide mode adapter to enlarge an optical mode near the output facet so that it is more closely matched to the mode in an optical fiber that carries the light away from the output facet.

69. The method of claim **68**, wherein the waveguide mode adapter includes a section of passive waveguide and the waveguide's cross section is varied to expand the waveguide's optical mode in an adiabatic manner.

70. The method of claim **39**, wherein the optical signal is tunable within a range of at least 15 nm.

71. The method of claim **39**, wherein the optically inactive areas are formed with multiple quantum well layers grow on top of the waveguide layer.

72. The method of claim **39**, wherein the optically active areas in the epitaxial structure are formed using off-set quantum wells.

73. The method of claim **39**, wherein the optically inactive areas in the epitaxial structure are formed by a selective area growth.

74. The method of claim **39**, wherein the optically inactive areas are formed by a selective area growth using a dielectric mask.

75. The method of claim **39**, wherein the optically inactive areas are formed by selective area disordering.

76. The method of claim **39**, wherein the optically inactive areas are formed by butt joint regrowth.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,654,400 B1 Page 1 of 1
DATED : November 25, 2003
INVENTOR(S) : Thomas Beck Mason, Gregory Fish and Larry Coldren

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 6,
Lines 2 and 3, "editorial" should read -- epitaxial --.
Line 63, "in" should read -- an --.

Signed and Sealed this

Sixteenth Day of March, 2004

JON W. DUDAS
Acting Director of the United States Patent and Trademark Office

EXHIBIT 3

US006687278B1

(12) **United States Patent**
Mason et al.

(10) **Patent No.: US 6,687,278 B1**
(45) **Date of Patent: Feb. 3, 2004**

(54) **METHOD OF GENERATING AN OPTICAL SIGNAL WITH A TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL AMPLIFIER**

(75) Inventors: **Thomas Beck Mason**, Middletown, NJ (US); **Gregory Fish**, Santa Barbara, CA (US); **Larry Coldren**, Santa Barbara, CA (US)

(73) Assignee: **Agility Communications, Inc.**, Goleta, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 211 days.

(21) Appl. No.: **09/614,665**

(22) Filed: **Jul. 12, 2000**

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/614,377, filed on Jul. 12, 2000, now Pat. No. 6,580,739, and a continuation-in-part of application No. 09/614,895, filed on Jul. 12, 2000, now Pat. No. 6,349,106, and a continuation-in-part of application No. 09/614,378, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,376, filed on Jul. 12, 2000, now Pat. No. 6,614,819, and a continuation-in-part of application No. 09/614,674, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,195, filed on Jul. 12, 2000, now Pat. No. 6,574,259, and a continuation-in-part of application No. 09/614,375, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,224, filed on Jul. 12, 2000.

(60) Provisional application No. 60/152,072, filed on Sep. 2, 1999, provisional application No. 60/152,049, filed on Sep. 2, 1999, and provisional application No. 60/152,038, filed on Sep. 2, 1999.

(51) **Int. Cl.**[7] **H01S 5/026**

(52) **U.S. Cl.** **372/50**; 372/20; 438/22

(58) **Field of Search** 372/50, 20; 438/22

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,773,074 A * 9/1988 Hunsperger et al. 372/50
4,802,182 A * 1/1989 Thornton et al. 372/50
4,896,325 A * 1/1990 Coldren 372/20
5,003,550 A * 3/1991 Welch et al. 372/50
5,084,894 A * 1/1992 Yamamoto 372/50
5,088,105 A 2/1992 Scifres et al. 372/92
5,379,318 A * 1/1995 Weber 372/96
5,396,511 A * 3/1995 Nakatsuka et al. 372/43
5,479,539 A 12/1995 Goldsmith et al. 385/14
5,525,541 A 6/1996 Krauz et al. 437/161
5,539,571 A * 7/1996 Welch et al. 359/344
5,625,636 A 4/1997 Bryan et al. 372/50
5,674,778 A 10/1997 Lee et al. 437/126
5,715,268 A 2/1998 Lang et al. 372/50
5,742,045 A 4/1998 Parker et al. 250/214
5,838,714 A * 11/1998 Delorme 372/96
5,914,480 A * 6/1999 Swartz 235/472.01
5,936,994 A * 8/1999 Hong et al. 372/96

FOREIGN PATENT DOCUMENTS

EP 1 539 028 1/1979 .... H01S/3/02
EP 0 620 475 A1 3/1994 .... G02F/1/313

OTHER PUBLICATIONS

Bar–Chaim, N. et al., "Monolithic Optoelectronic Integration of a GaAIAs Laser, a Field–Effect Transistor, and a Photodiode", *Applied Physics Letters, US, American Institute of Physics*, May 15, 1984, vol. 44, No. 10, pp. 941–943.

(List continued on next page.)

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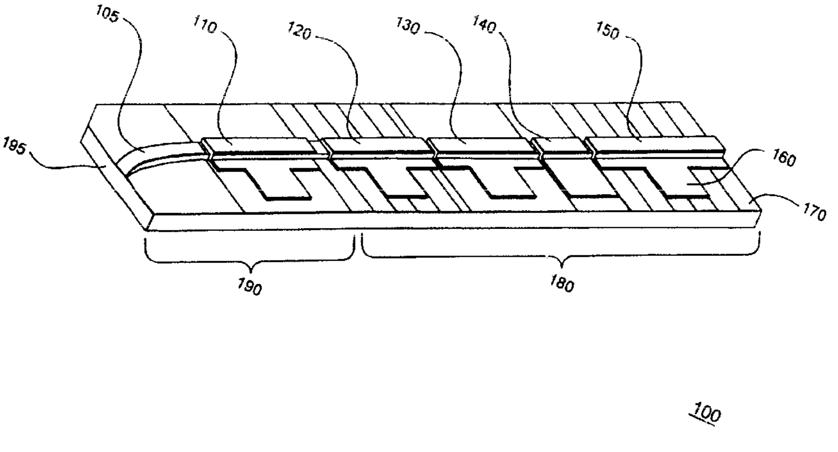
(57) **ABSTRACT**

A method of generating an optical signal provides a diode laser assembly including an epitaxial structure formed on a substrate. A laser and an amplifier are formed in the epitaxial structure. At least a portion of the laser and amplifier share a common waveguide. A tunable laser output is produced from the laser. The laser output is coupled into the amplifier along the common waveguide. An optical signal is generated from the amplifier.

26 Claims, 7 Drawing Sheets



OTHER PUBLICATIONS

Koch, T.L., "Semiconductor Photonic Integrated Cicruits", *IEEE Journal of Quantum Electronics*, Mar. 27, 1991, No. 3, pp. 641–653.

Byoung–Sung, K. et al., "Dynamic Analysis of Widely Tunable Laser Diodes Integrated with Sampled–and-Chirped–Grating Distributed Bragg Reflectors and an Electroabsorption Modulator", *IEICE Trans Electron*, Aug. 1998, vol. E81–C, No. 8, pp. 1342–1349.

San–Liang, L. et al., "Sampled Grating DBR Laser Arrays with Adjustable 0.8/1.6–nm Wavelength Spacing", *IEEE Photonics Technology Letters*, Aug. 1999, vol. 11, No. 8, pp. 955–957.

Jayaraman, V. et al., "Theory, Design, and Performance of Extended Tuning Range Semiconductor Lasers with Sampled Gratings", *IEEE Journal of Quantum Electronics*, Jun. 29, 1993, vol. 29, No. 6, pp. 1824–1834.

* cited by examiner

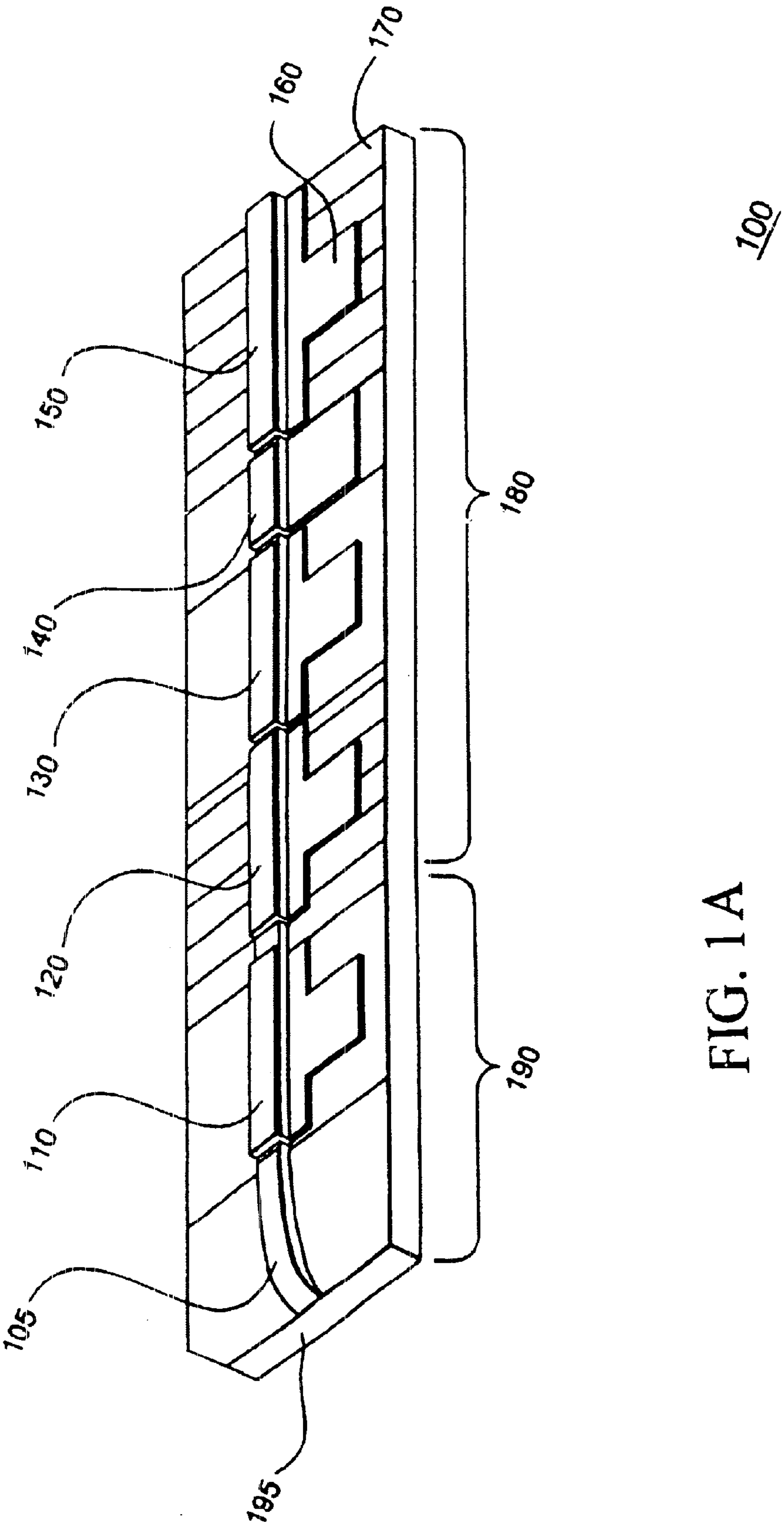


FIG. 1A

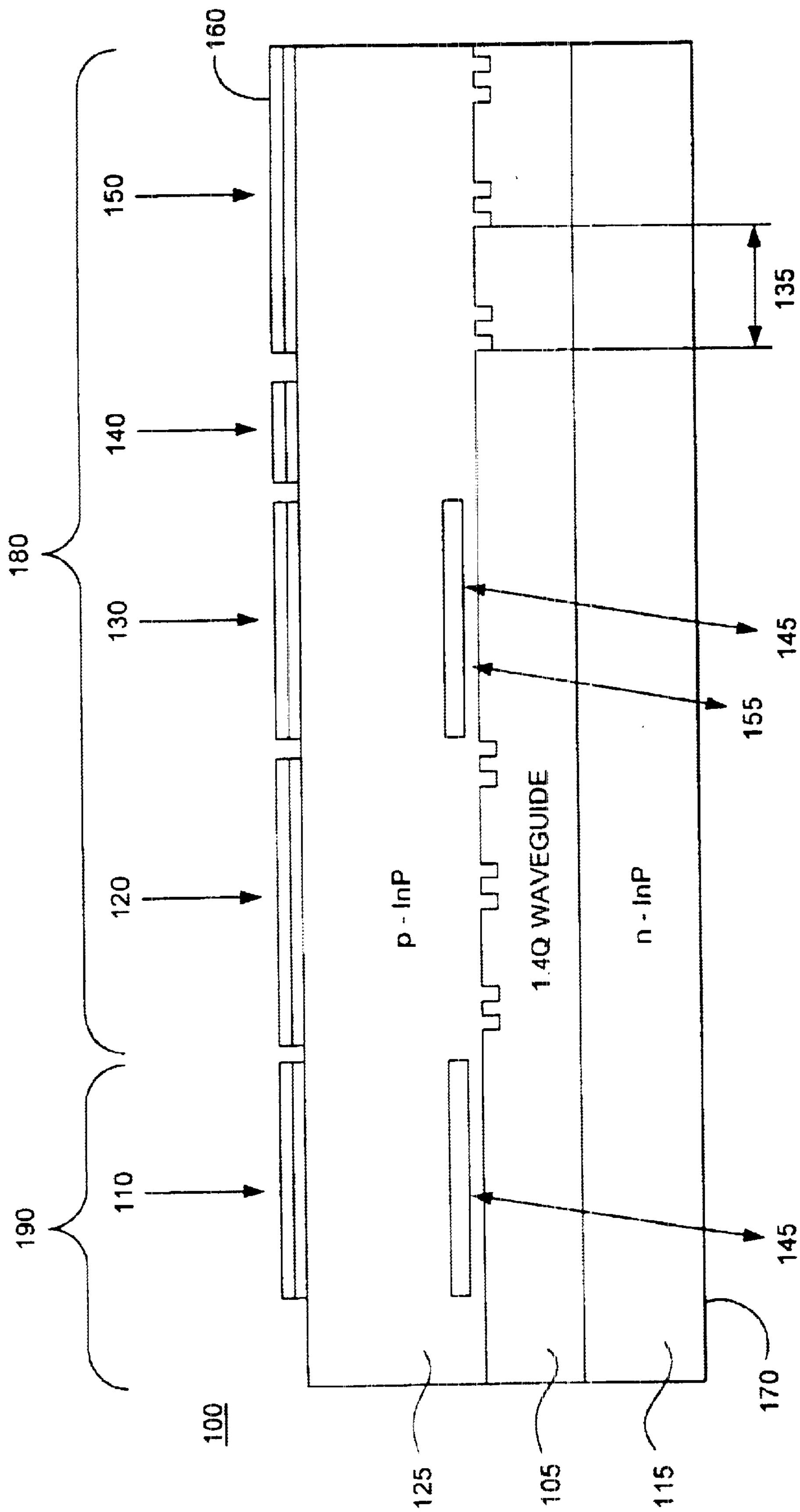

160
150
140
130
120
110
180
190
135
145
155
145
p - InP
1.4Q WAVEGUIDE
n - InP
170
100
125
105
115

FIG. 1B

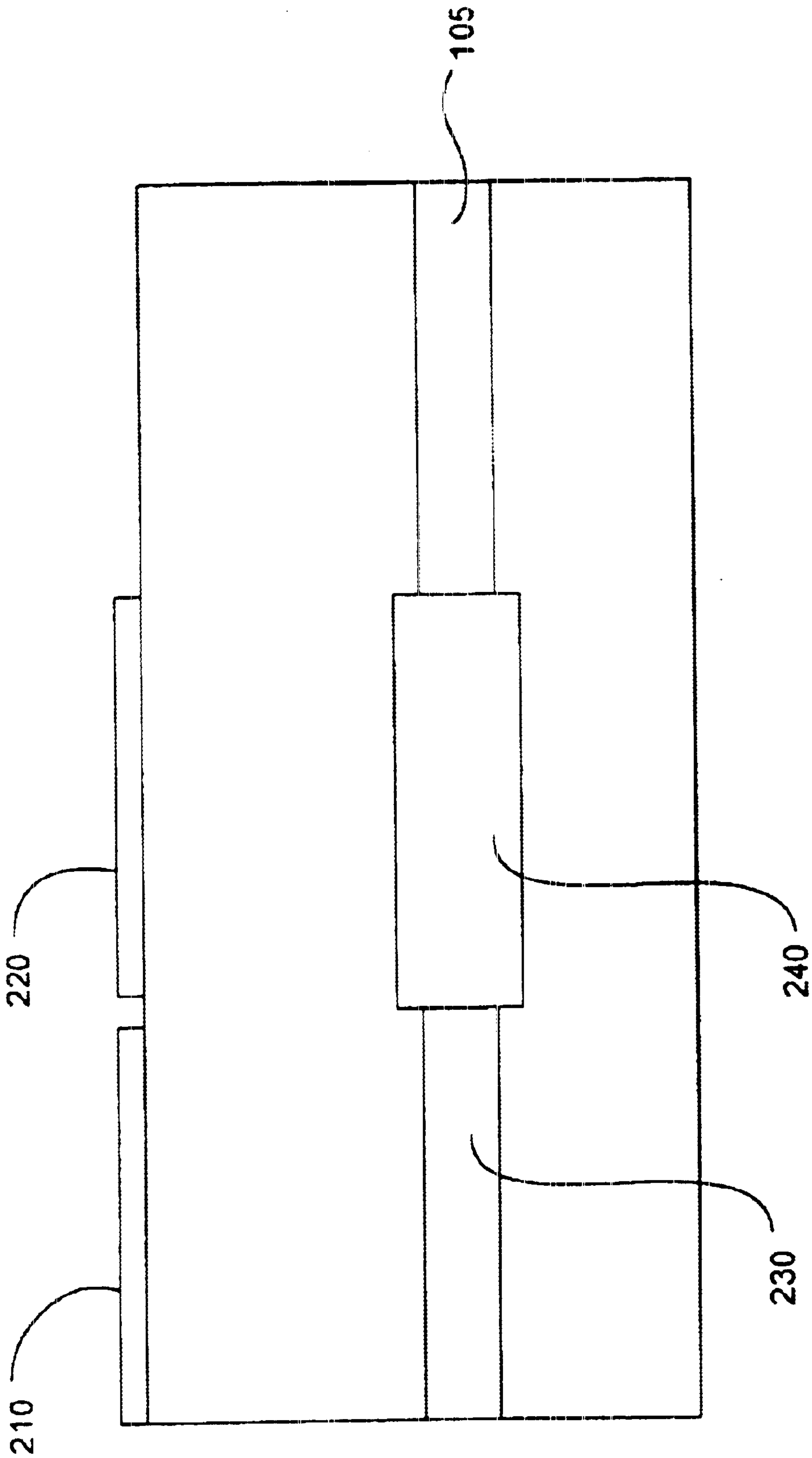


FIG. 2A

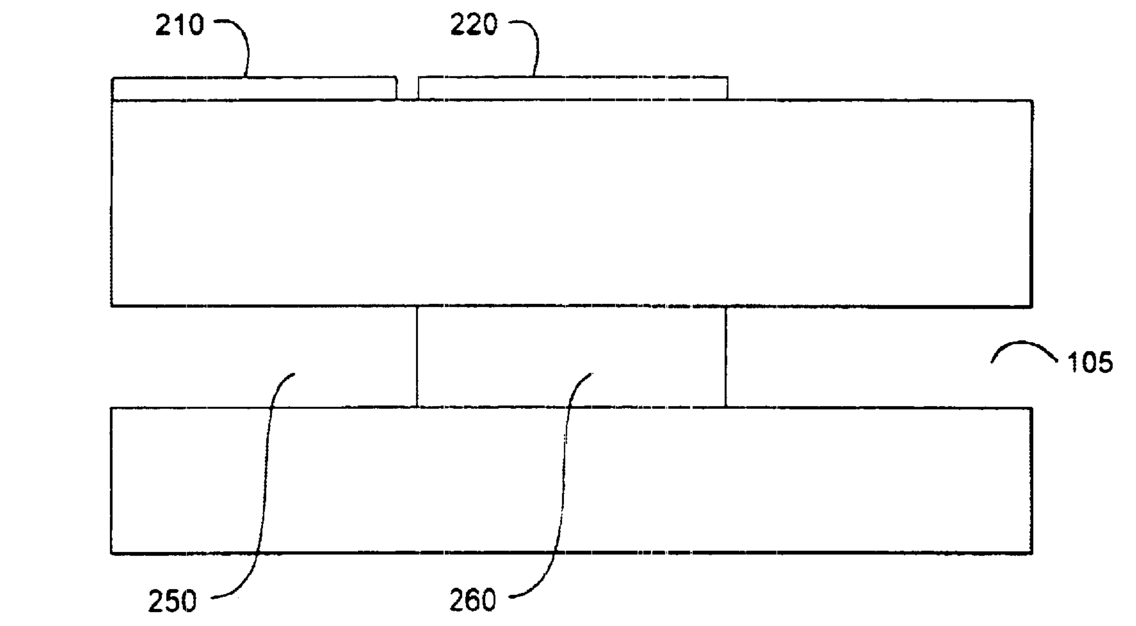


FIG. 2B

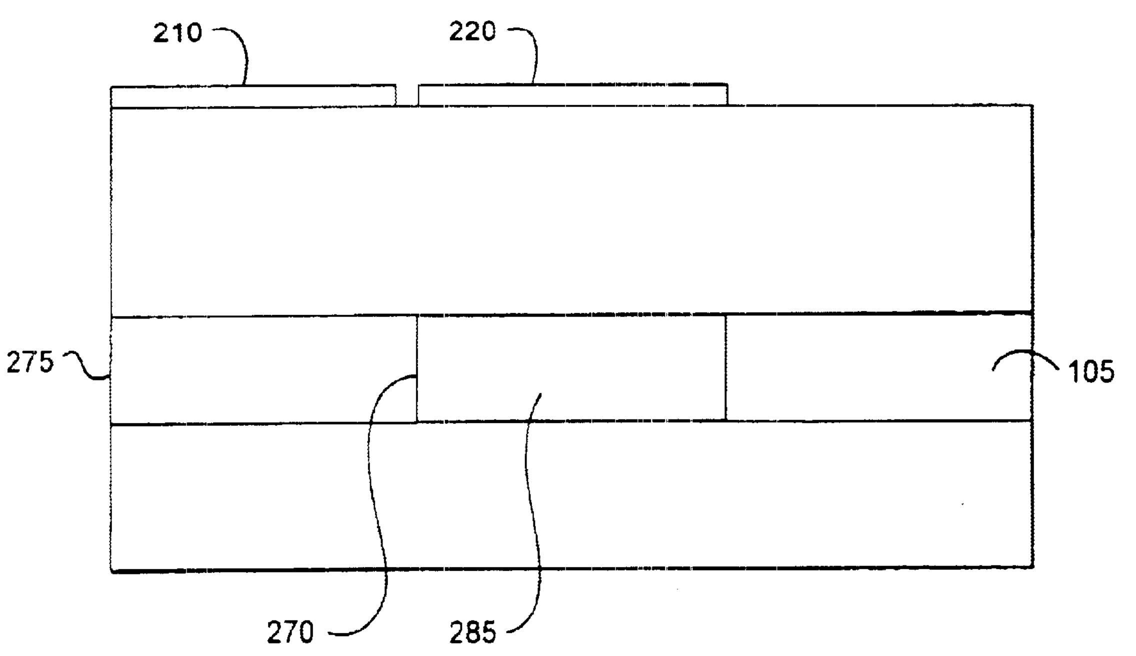


FIG. 2C

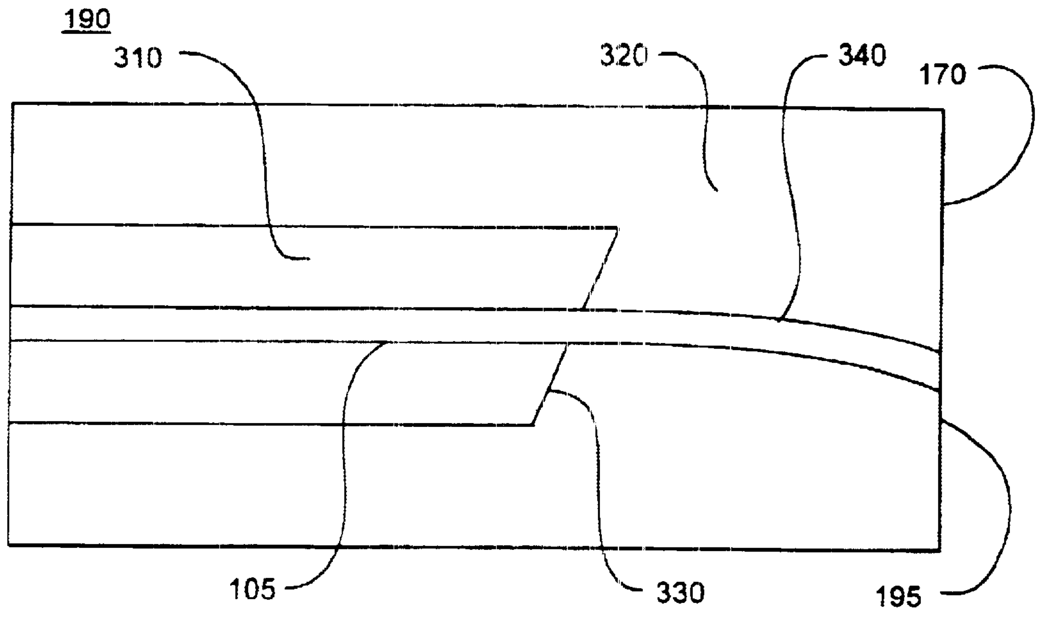


FIG. 3A

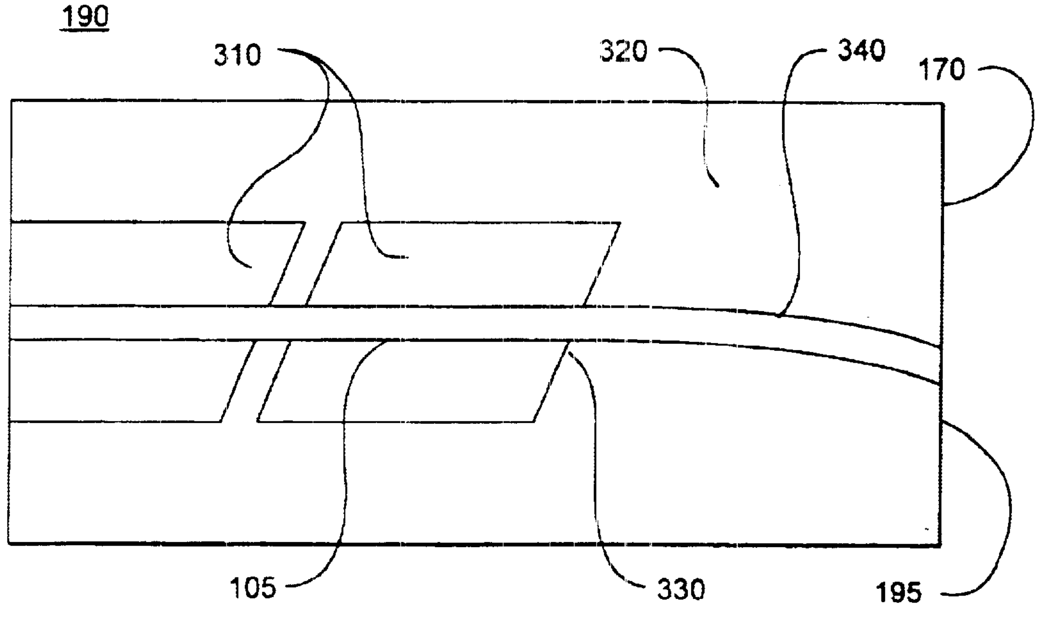


FIG. 3B

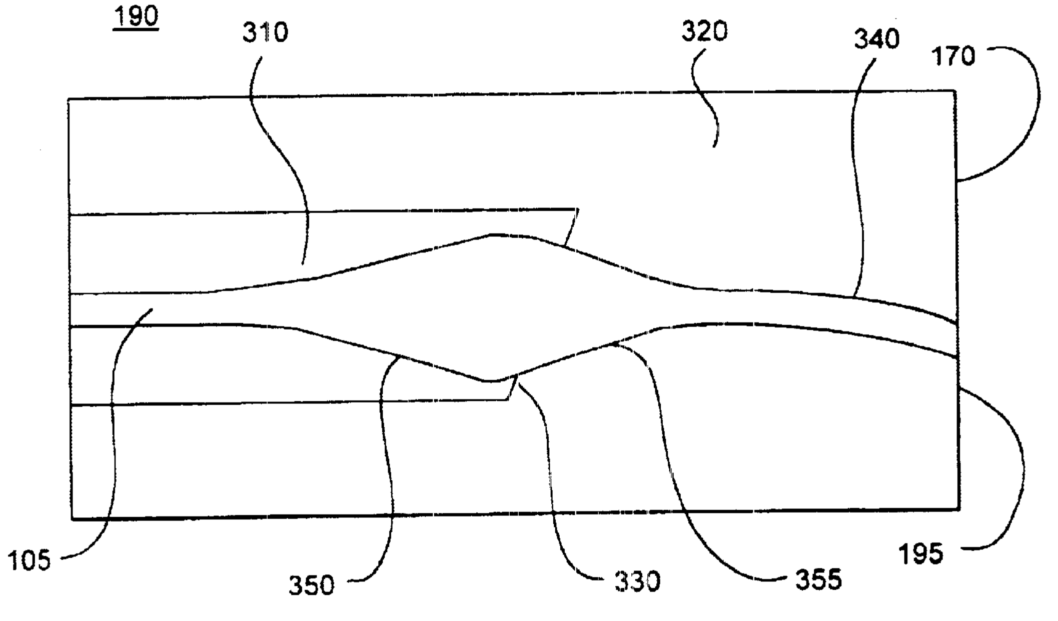


FIG. 3C

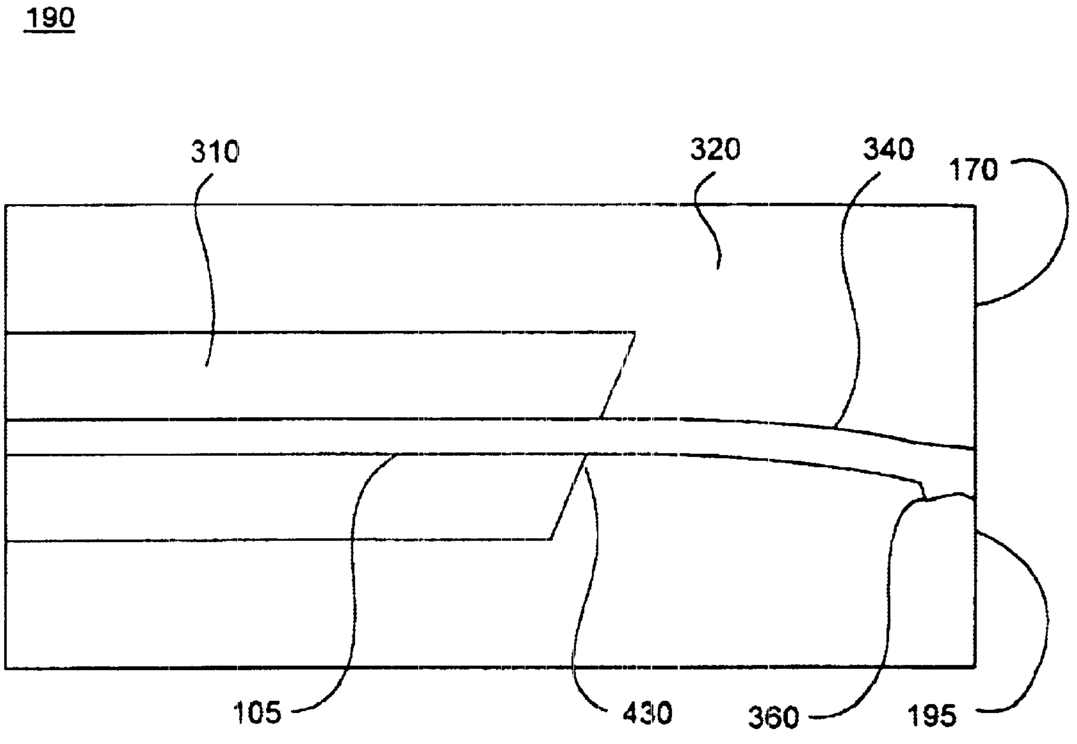


FIG. 3D

METHOD OF GENERATING AN OPTICAL SIGNAL WITH A TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL AMPLIFIER

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part and claims the benefit of priority of U.S. Provisional Application Ser. No. 60/152,072, filed Sep. 2, 1999, U.S. Provisional Application Ser. No. 60/152,049, filed Sep. 2, 1999, U.S. Provisional Application Ser. No. 60/152,038, filed Sep. 2, 1999, which applications are fully incorporated by reference herein. This application is also a continuation-in-part of U.S. Ser. Nos. 09/614/377 now U.S. Pat. No. 6,580,739, **09/614,895**(now U.S. Pat. No. 6,349,106, issued Feb. 19, 2002), Ser. Nos. 09/614,674, 09/614,378, 09/614,376 now U.S. Pat. No. 6,614,819, **09/614,195**now U.S. Pat. No. 6,574,259, **09/614, 375**and 09/614,224, filed on the same date as this application, which applications are fully incorporated by reference herein.

FIELD OF THE INVENTION

This invention relates generally to laser assemblies, and more particularly to a widely tunable laser assembly with an integrated optical amplifier.

BRIEF DESCRIPTION OF THE RELATED ART

Thin fibers of optical materials transmit light across a very broad frequency bandwidth and therefore communications data from a light source may be transmitted over such fibers over broad frequency ranges. At any particular frequency, a laser source must have high output power, narrow laser linewidth and good transmission performance through great distances of optical fiber.

In higher bandwidth communications systems, where many frequencies of laser light are transmitted along a fiber, there may be one or several laser sources. While a tunable laser source would be preferred, higher data capacity systems presently use multiple laser sources operating on different frequency channels to cover the wide fiber transmission bandwidth. This is the case since appropriate laser sources are presently incapable of rapid, electronic frequency tuning without attendant deterioration of other significant figures-of-merit.

For example, at a fixed frequency, sampled grating distributed Bragg reflector (SGDBR) lasers have the high output power, narrow laser linewidth and good transmission performance necessary for an optical data network. While some SGDBR lasers can be rapidly tuned over more than 100 different transmission channels, two problems nevertheless prevent these devices from being employed in fiber optic communication systems. The most significant problem is the significant absorption of the mirror material. The resulting large cavity losses act to make the laser output power insufficient for the requirements of a present-day communications system. A second problem is that the output power and frequency tuning are dependent on each other. This coupling results in inadequate controllability for a present-day communications system.

What is needed, instead, is a device with a combination of sufficiently high output power for a high-bandwidth optical communications network and with frequency tuning controllability substantially independent of output power controllability.

SUMMARY

Accordingly, an object of the present invention is to provide an integrated laser assembly that includes a tunable solid state laser and optical amplifier where all of the elements are fabricated in a common epitaxial layer structure.

Another object of the present invention is to provide an integrated laser assembly that includes a tunable solid state laser and optical amplifier with an output mode conditioned for transmission in an optical fiber.

Another object of the present invention is to provide an integrated laser assembly that includes a tunable laser and optical amplifier reducing optical feedback from the amplifier to the laser.

A further object of the present invention is to provide a tunable, integrated laser assembly where laser frequency control and output power control are substantially independent.

These and other objects of the present invention are achieved in a laser assembly that includes an epitaxial structure formed on a substrate. A tunable laser resonator and a separately controllable optical amplifier are formed in the common epitaxial structure. The amplifier is positioned outside of the laser resonator cavity to receive and adjust an output received from the laser, however, at least a portion of the laser and amplifier share a common waveguide.

In different embodiments of the present invention, properties of the common waveguide such as optical properties, or centerline curvature or cross-sectional are non-uniform along the waveguide centerline or non-uniform across a normal to the centerline.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1**A is a block diagram of a laser assembly that illustrates different functional elements of a laser assembly.

FIG. **1**B is a cross-sectional view of one embodiment of a widely tunable laser assembly of the present invention and the integration of materials with differing optical properties by an offset quantum well technique.

FIG. **2**A is a cross-sectional view of one embodiment of an amplifier illustrating several layer structures and the integration of two materials with differing optical properties by a selected area growth technique.

FIG. **2**B is a cross-sectional view of the FIG. **2** assembly illustrating one embodiment for the integration of materials with differing optical properties by a disordered well technique.

FIG. **2**C is a cross-sectional view of one embodiment of an amplifier illustrating one embodiment for the integration of several different band gap materials by a butt joint regrowth technique.

FIG. **3**A is a cross-sectional view of one embodiment of the FIG. **1** optical amplifier element where a portion of the waveguide is curved and an interface between an active and a passive section is oblique.

FIG. **3**B is a cross-sectional view of one embodiment of the FIG. **1** optical amplifier element where the amplifier includes a plurality of gain sections.

FIG. **3**C is a cross-sectional view of one embodiment of the FIG. **1** optical amplifier element where the amplifier includes a flared waveguide.

FIG. **3**D is a cross-sectional view of one embodiment of the FIG. **1** optical amplifier element where the amplifier includes a waveguide mode adapter.

DETAILED DESCRIPTION

FIG. **1**A shows a schematic of an embodiment of the invention. In FIG. **1**A, laser assembly **100**, waveguide **105**,

amplifier gain section **110**, front resonator mirror **120**, laser gain section **130**, laser phase control section **140**, back mirror **150** and electrical contact **160**, epitaxial structure **170**, laser **180**, optical amplifier **190** and output facet **195** are shown.

In FIG. **1**A, laser assembly **100** comprises an integration of a laser and an optical amplifier, with the optical amplifier located external to the laser cavity. Front resonator mirror **120**, laser gain section **130**, laser phase control section **140**, and back mirror **150** form a SGDBR-type laser **180** in epitaxial structure **170**. The front and back mirrors define a laser cavity. Amplifier gain section **110** and a portion of waveguide **105** define optical amplifier **190**.

As shown in FIG. **1**A, despite being external to the laser cavity, the optical amplifier shares a common epitaxial structure **170** with the laser. Epitaxial structure **170** is formed on a substrate (not shown) by processes well-known in the art of semiconductor fabrication. By tailoring optical properties (such as band gap) of different portions of the epitaxial structure, both optically active and optically passive sections can be fabricated in a common structure. Examples of optically active sections of the embodiment shown in FIG. **1** are gain sections **110** and **130**, phase control section **140** and mirrors **120** and **150**. An example of an optically passive section is the portion of waveguide **105** proximal to output facet **195**.

According to the invention, at least a portion of laser **180** and optical amplifier **190** share a common waveguide **105**. Different portions of the common waveguide may extend through optically active or passive regions. A common waveguide for the laser and optical amplifier enables the output from the laser to be directly coupled into the amplifier.

In the embodiment of FIG. **1**A, amplifier **190** is external to the resonant cavity of laser **180** formed by mirrors **120** and **150**. Moreover, amplifier gain section **110** is separately controllable from the laser and is adjustable to increase or decrease the light intensity and output power. The SGBDR laser elements may be controlled separately from the amplifier to tune the laser frequency and otherwise control the input to the optical amplifier. By this arrangement of elements, power amplification and tuning functions are substantially uncoupled.

In the embodiment of FIG. **1**A, optical amplifier **190** has an active section and a passive section. The active section, amplifier gain section **110**, is substantially straight. The passive section of waveguide **105** is curved and intersects output facet **195** at an oblique angle. Both waveguide curvature and the oblique intersection with the output facet act to prevent reflections at the output facet from coupling back into the optical amplifier **190** and laser **180**.

FIG. **1**B shows a longitudinal cross section of a laser assembly **100** of FIG. **1**A. In FIG. **1**B, laser assembly **100**, waveguide **105**, amplifier gain section **110**, front resonator mirror **120**, laser gain section **130**, laser phase control section **140**, back mirror **150** and electrical contact **160**, epitaxial structure **170**, laser **180**, optical amplifier **190**, output facet **195**, p type semiconductor layer **125**, n-type semiconductor layer **115**, mirror sampling period **135**, offset quantum wells **145** and stop etch layer **155** are shown.

In FIG. **1**B waveguide **105** is formed between p-type and n-type semiconductor layers **125** and **115**, respectively. Mirrors **120** and **150** are formed by sample gratings etched in waveguide **105** with sampling period **135**, as is well-understood in the art.

FIG. **1**B illustrates the structure resulting from an offset quantum well technique for optically active and passive section formation. According to the offset quantum well technique, the optically active sections have multiple quantum well layers **145** grown in a region offset from waveguide **105**. The multiple quantum well layers are separated from the waveguide by a thin stop etch layer **155**. Removal of quantum wells, by etching for example, forms optically passive sections.

FIGS. **2**A–**2**C illustrate cross-sectional structures over a portion of laser assembly **100** (see FIG. **1**) resulting from different techniques for forming optically active and passive sections and their junctions. FIG. **2**A illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. **1**) resulting from a selected area regrowth technique. The selected area regrowth technique uses a dielectric mask to selectively control the growth rate and composition over different areas of the epitaxial structure. Thus, the material's bandgap can be shifted in certain sections making the material in that section passive or non-absorbing at desired wavelengths. In FIG. **2**A, optically passive section **210**, optically active section **220**, bandgap-shifted quantum wells **230**, active section quantum wells **240**, and waveguide **105** (see FIGS. **1**A–**1**B) are shown. In FIG. **2**A, different portions of waveguide **105** are optically active or passive due to bandgap-shifting of the quantum wells within the waveguide.

FIG. **2**B illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. **1**) resulting from a selected area disordering technique for forming optically active and passive sections. The selected area disordering technique uses a dielectric cap or ion implantation to introduce vacancies which can be diffused through an active region to disorder the quantum wells by intermixing them. This disordering shifts quantum well bandgaps, creating optically passive waveguide sections.

In FIG. **2**B, optically passive section **210**, optically active section **220**, disordered wells **250**, active section multiple quantum wells **260**, and waveguide **105** (see FIGS. **1**A–**1**B) are shown. In FIG. **2**B, different portions of waveguide **105**, sections **210** and **220**, are optically active or passive due to the organization of the quantum wells within the waveguide material.

FIG. **2**C illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. **1**) resulting from a butt joint regrowth technique for forming optically active and passive sections. According to the butt joint regrowth technique, the entire waveguide is etched away in optically passive sections and an optically passive waveguide is grown again. The newly grown portion of the waveguide is butted up against the active waveguide. In FIG. **2**B, optically passive section **210**, optically active section **220**, active, butt-joint interface **270**, passive waveguide section **275**, active waveguide section **285** and waveguide **105** (see FIGS. **1**A–**1**B) are shown. In FIG. **2**B, active waveguide section **285** and passive waveguide section **275** are separated by a distinct large gradient butt-joint interface **270** as a result of the etch removal process.

FIGS. **3**A–**3**D are plan views, illustrating different embodiments of optical amplifier **190** (see FIG. **1**). In FIGS. **3**A–**3**D optical amplifier **190**, waveguide **105**, epitaxial structure **170**, output facet **195**, active amplifier section **310**, passive amplifier section **320**, active-passive junction **330**, curved waveguide portion **340**, flared waveguide portions **350** and **355** and waveguide mode adapter **360** are shown.

In FIG. **3**A. optical amplifier **190** has an active amplifier section **310** combined with a passive amplifier section **320**, where the passive amplifier section includes curved

waveguide portion **340**. The curved waveguide portion intersects output facet **195** at an oblique angle. Both the waveguide curvature and oblique intersection significantly reduces the amount of light reflecting from the output facet back into the amplifier and laser. Active-passive junction **330** is preferably oblique to a centerline of wave guide **105** so that any reflections from this interface coupling back into the amplifier and laser will be reduced. However, alternate embodiments may have active-passive junction **330** substantially normal to a centerline of the waveguide.

FIG. **3**B shows an alternate embodiment where the amplifier active section has been segmented into a plurality of active sections in order to increase the amplifier output power and reduce a noise figure. In this embodiment shown in FIG. **3**B, the amplifier active section is segmented into two amplifier active sections **310** that may be independently controllable. Other embodiments have more than two amplifier active sections. This segmenting of the amplifier enables the use of different bias points for the different sections. Having a plurality of amplifier stages allows higher saturated output powers to be reached with better noise performance.

FIG. **3**C shows an alternate embodiment where a waveguide portion in the amplifier active section is flared, or tapered, to increase the saturated output power. Flared waveguide portion **350** increases the amplifier active volume as compared to the embodiment shown in FIG. **3**A and decreases the photon density. To accomplish this effectively without introducing significant fiber coupling difficulties it is preferable to use an adiabatic flare, wherein there is no energy transfer across optical modes over the flare to a wider waveguide cross-section. In a preferred embodiment, a second flared-down section **355** to a narrow waveguide cross-section is positioned in the amplifier optically passive section **320** since it is difficult to couple effectively from a wide waveguide into a single mode fiber at output facet **195**. In a preferred embodiment, such a flared-down portion is before a curved waveguide portion **340**, otherwise, higher order modes will be excited when curving the wide waveguide. In the embodiment shown in FIG. **3**C, active-passive junction **330** is angled so that any reflections from this interface coupling back into the amplifier and laser will be reduced.

FIG. **3**D shows another embodiment including a waveguide mode adapter. A waveguide mode adapter is preferred in many embodiments to enlarge the optical mode near output facet **195** so that it is more closely matched to the mode in an optical fiber that, as an element in a communications system, may carry the light away from the output facet. Including a waveguide mode adapter thus reduces the fiber coupling loss and increases the alignment tolerances between laser assembly **100** (see FIG. **1**) and an optical fiber of another system. An embodiment of a waveguide mode adapter includes a section of passive waveguide wherein the waveguide's cross sectional is varied to expand the waveguide optical mode in an adiabatic manner.

The foregoing description of a preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in this art. It is intended that the scope of the invention be defined by the following claims and their equivalents.

The foregoing description of a preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in this art. It is intended that the scope of the invention be defined by the following claims and their equivalents.

What is claimed is:

1. A method of generating an optical signal, comprising:

providing a diode laser assembly including an epitaxial structure formed on a substrate, a laser and an amplifier formed in the epitaxial structure, the laser including first and second reflectors, a gain section and a phase section, the gain section and the phase section each being positioned between the first and second reflectors to produce a tunable laser output therefrom, at least a portion of the laser and an amplifier sharing a common waveguide formed in the epitaxial structure, wherein at least a portion of the common waveguide is curved to reduce reflections from an output facet;

coupling the laser output into the amplifier along the common waveguide; and

generating an optical signal from the amplifier in response to the coupled laser output.

2. The method of claim **1**, wherein the optical signal is generated while controlling an intensity of the laser output and maintaining a constant laser wavelength.

3. The method of claim **1**, wherein the curved portion of the common waveguide reduces an amount of light reflecting into the amplifier and laser.

4. The method of claim **1**, further comprising a waveguide mode adapter to enlarge an optical mode near the output facet, so that it is more closely matched to a mode in an optical fiber.

5. The method of claim **1**, wherein laser output is tunable over a tuning range while maintaining a substantially constant output power.

6. The method of claim **1**, wherein laser output is tunable over a tuning range of at least 15 nm while maintaining a substantially constant output power.

7. The method of claim **1**, wherein the optical signal is generated while alternating a propagation direction of the laser output within the amplifier.

8. The method of claim **1**, wherein the optical signal is generated while minimizing back reflections into the laser.

9. The method of claim **1**, wherein the optical signal is generated while alternating at least one optical mode in the amplifier.

10. The method of claim **9**, wherein altering the optical modes is an adiabatic mode expansion.

11. The method of claim **1**, wherein the optical signal is generated while selectively exciting waveguide modes in the amplifier.

12. The method of claim **1**, wherein the curved portion of the common waveguide intersects the output facet at an oblique angle.

13. The method of claim **12**, wherein both the curved portion of the common waveguide and the oblique angle reduce an amount of light reflecting from the output facet back into the amplifier and laser.

14. A method of generating an optical signal, comprising:

providing a diode laser assembly including first and second semiconductor layers in an epitaxial structure, a waveguide formed between the first and second semiconductor layers in the epitaxial structure, and a laser and an amplifier formed in the epitaxial structure, the laser including a gain section and a phase section each being positioned between two grating sections to pro-

duce a tunable laser output therefrom, wherein at least a portion of the waveguide is curved to reduce reflections from an output facet;

coupling the laser output into the amplifier along the waveguide;

propagating the laser output in a tapered section of the waveguide in the amplifier to increase saturated output power; and

generating an optical signal from the amplifier in response to the propagated laser output.

15. The method of claim **14**, wherein the optical signal is generated while controlling an intensity of the laser output and maintaining a constant laser wavelength.

16. The method of claim **14**, wherein the laser output is tunable over a tuning range while maintaining a substantially constant output power.

17. the method of claim **14**, wherein the laser output is tunable over a tuning range of at least 15 nm while maintaining a substantially constant output power.

18. The method of claim **14**, wherein the optical signal is generated while alternating a propagation direction of the laser output within the amplifier.

19. The method of claim **14**, wherein the optical signal is generated while minimizing back reflections into the laser.

20. The method of claim **14**, wherein the optical signal is generated while altering at least one optical mode in the amplifier.

21. The method of claim **20**, wherein altering the optical modes is an adiabatic mode expansion.

22. The method of claim **14**, wherein the optical signal is generated while selectively exciting waveguide modes in the amplifier.

23. The method of claim **14**, wherein the curved portion of the waveguide reduces an amount of light reflecting into the amplifier and laser.

24. The method of claim **14**, wherein the curved portion of the waveguide intersects the output facet at an oblique angle.

25. The method of claim **24**, wherein both the curved portion of the waveguide and the oblique angle reduce an amount of light reflecting from the output facet back into the amplifier and laser.

26. The method of claim **14**, further comprising a waveguide mode adapter to enlarge an optical mode near the output facet, so that it is more closely matched to a mode in an optical fiber.

* * * * *